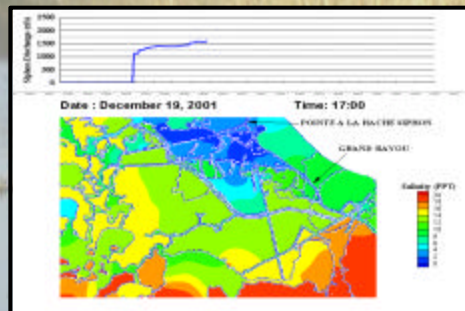
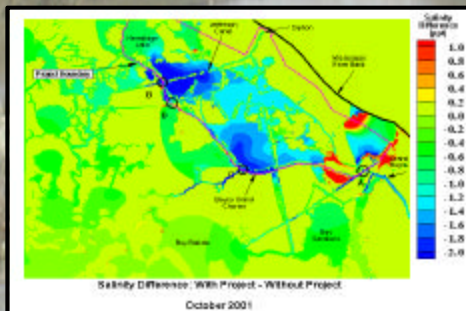




# HYDRODYNAMIC MODELING

of the

## WEST POINTE A LA HACHE OUTFALL MANAGEMENT PROJECT (BA-4C)



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(Revised: November 2005)

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## TABLE OF CONTENTS

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Description	Page
<b>Executive Summary</b>	
<b>Chapter 1</b>	
1.1 Project Background and Objective	1
1.2 Analysis Approach	4
1.3 Project Description	5
<b>Chapter 2</b>	
2.1 Model Selection	12
2.1.1 Model Resolution	14
2.2 Data Collection and Review	14
2.2.1 Bathymetric and Topographic Data	14
2.2.2 Hydrologic Data Collection	31
<b>Chapter 3</b>	
3.1 Model Setup	34
3.2 Model Boundary Conditions	36
3.3 Model Calibration	36
3.3.1 Analysis of Field Data	37
3.3.2 Numerical Model Results	51
3.3.3 Tide Analysis	62
3.3.4 Survey of Monitoring Stations Vertical Datum	76
3.4 Discussion of Model Calibration Results	79
<b>Chapter 4</b>	
4.1 Initial Assessment of Project Features	80
4.2 Further Assessment of Project Features	82
4.2.1 Analysis of Field Data for July 2001 to June 2002	82
4.2.2 Model Validation for July 2001 to June 2002	83
4.2.3 Final Assessment of Project Features	86
4.2.4 Salinity and Water Level Map Analysis	86
4.3 Conclusions and Closing Remarks	87
<b>Appendix</b>	
Monthly Average Salinity Change Maps	

## EXECUTIVE SUMMARY

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The West Pointe a la Hache Outfall Management Project (BA-4C) is a Coastal Wetlands Planning, Protection, and Restoration Act project located within the Barataria Basin in Plaquemines Parish, Louisiana. The proposed project is anticipated to reduce project area wetland loss rates by enhancing the distribution of sediments and nutrients in the outfall from the West Pointe a la Hache siphon, and by reducing saltwater intrusion into the project area through both Barataria Bay and Grand Bayou. As a result, emergent wetlands will be enhanced and aquatic vegetation is expected to increase.

Presently, the proposed project features include various fixed crested rock weirs with barge and boat bays, earthen plugs, and spoil bank maintenance. C.H. Fenstermaker & Associates (CHF) was retained to perform a thorough assessment of effectiveness of these proposed project features. A three-dimensional unsteady hydrodynamic and salinity numerical model was used to perform the analysis under various tidal and freshwater siphon discharge conditions.

The intention of this report is to outline the complete process involved in setting up, calibrating, and validating the numerical model, as well as assessing the project features. This process starts with understanding the project objectives, selecting the appropriate computer model to conduct the analysis, and concludes with recommendations. The following is a list of the main components of the report:

- ?? Model selection
- ?? Model resolution (spatial and grid)
- ?? Bathymetric data sources and collection techniques
- ?? Availability of hydrologic data
- ?? Model Setup
- ?? Model calibration and validation
- ?? Evaluation of the model performance
- ?? Discussion of limitations & capabilities of the model
- ?? Assessment of the project features

The evaluation and assessment of the project features were based on both time series plots showing water and salinity levels at pre-selected locations, and salinity and water level plan-view maps presented as temporal animations with specified time intervals.

The comparison of salinity and water levels for simulations of “with” and “without” project features (illustrated in figures 4.44 through 4.51) indicate that the proposed project features result in small reduction in salinities. In an attempt to maximize the benefits of the project features, the proposed structure openings were reduced in size. These modifications to the structure sizes resulted in very small reduction in salinities in the order of two parts per thousand (p.p.t.).

**C.H. Fenstermaker & Associates, Inc.**

This study also showed that the freshwater siphon at West Point a la Hache reduces the salinity levels within the project area significantly. The study showed that the proposed project features did not significantly lower salinities beyond the salinity reductions already achieved by the freshwater siphon.

It should also be noted that additional surveying was performed during the modeling process in an effort to help understand and eliminate assumptions that the bank lines of Bayou Grand Chenier were of a constant elevation.

An amendment was made to the report in November of 2005 to include monthly-average salinity maps for the time period of August 2001 to July 2002 as requested by the governmental agencies. The maps show spatial distribution of the difference in the monthly average salinity of the existing conditions and with-project conditions. The maps are a good tool to evaluate the impact of the project features on the spatial salinity distribution in the area of interest.

The scope of this study does not include any analyses regarding biological nor ecological benefits resulting from the proposed project features.



# I. CHAPTER ONE

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## 1.1 PROJECT BACKGROUND AND OBJECTIVE

The services of C.H. Fenstermaker and Associates, Inc. (CHF) have been retained by the Louisiana Department of Natural Resources (LDNR) and the Natural Resources Conservation Service (NRCS) to study the effects of proposed structures of the West Pointe A La Hache Outfall Management Project (BA-4C). It is a Coastal Wetlands Planning, Protection, and Restoration Act project located within the Barataria Basin in Plaquemines Parish, Louisiana (shown on Figure 1.1). The federal sponsor for the project is NRCS, and the local sponsor is LDNR. The project area shown in Figure 1.2 is bounded to the north by Lake Judge Perez, to the west and southwest by Bayou Grande Chenier, to the southeast by the Tennessee Gas Pipeline Canal, and to the east by the West Point a la Hache hurricane protection levee.

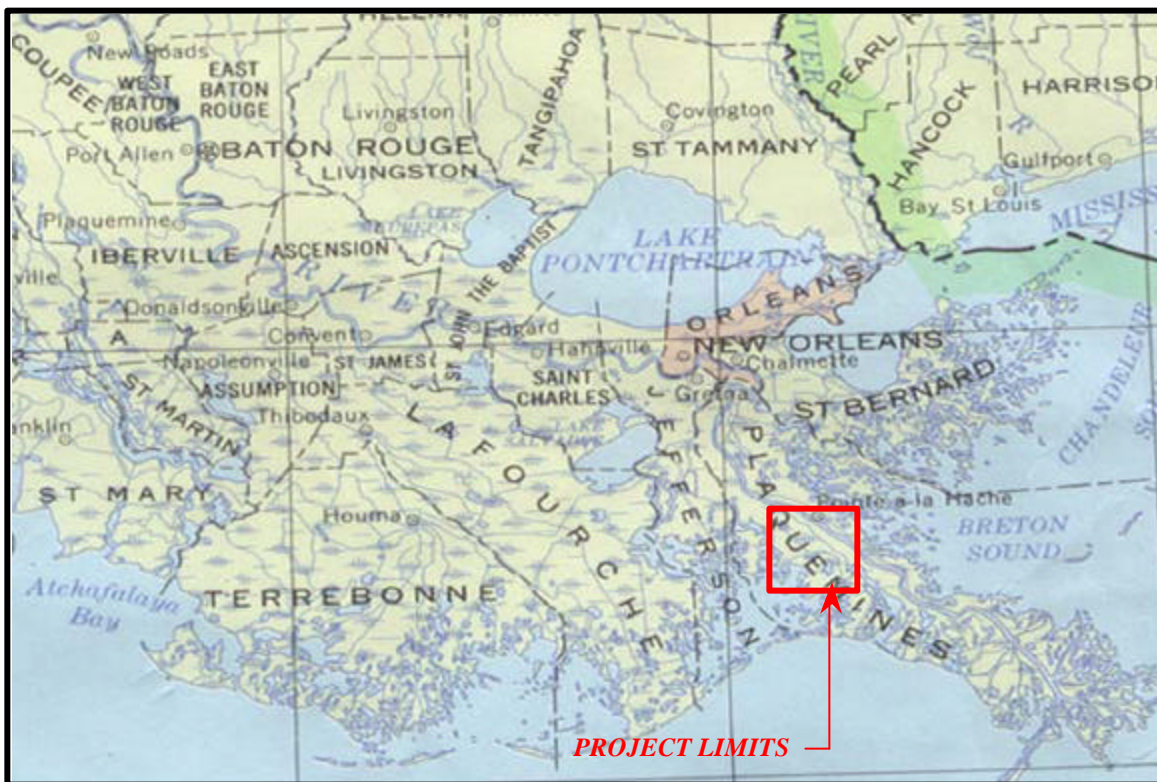


Figure 1.1: Project Vicinity Map

The project area consists of approximately 16,900 acres, 7,600 of which are brackish marsh and 9,300 are open water. The project includes a freshwater introduction siphon, located at Mississippi River mile 48.9 (above head of passes) and shown in Figure 1.3, which consists of eight 78" diameter siphon tubes that have a combined maximum discharge of 2,144 cubic feet per second. The siphon's main functions are to help retard

saltwater intrusion into the project area from the Gulf of Mexico through the Barataria Basin, and to increase overland flow distribution of freshwater throughout the project area.

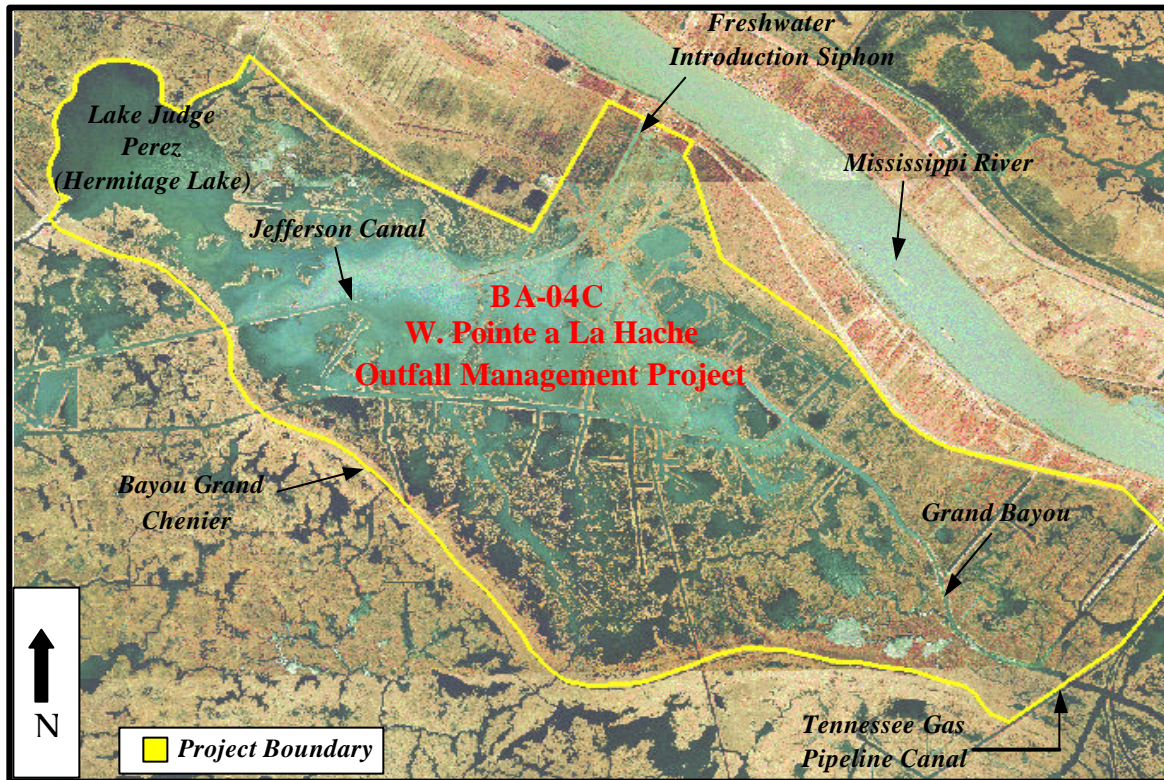


Figure 1.2: Project Area





Figure 1.3: West Point a La Hache Siphon

The Barataria Basin has been adversely affected by the construction of the flood control levees along the Mississippi River (Figure 1.3). The construction of the levee system has prevented the natural introduction of freshwater and sediment into this basin. In addition to the reduction of freshwater and sediment into the basin, natural subsidence has also created a negative impact on this area.

The project area, which is within the Barataria Basin, has experienced a reduction in marsh area since the 1930's. Current records indicate that several factors have impacted the overall hydrologic conditions of the project area. These factors include the West Pointe a la Hache Siphon, the West Mississippi River Flood Protection Levee, the Texaco Pipeline Canal, and various other earth plugs, canals, and oilfield slip canals. This conceptual project aims to decrease the loss of marsh area resulting from these features.

A numerical model was used to determine the effectiveness of the proposed project structures. It will also help the various state and federal agencies understand the dynamics of the project's area. Most importantly, this model is aimed to provide accurate information about the water level and salinity fluctuations within the project area. Finally, proposed hydraulic structures within the project boundary will be added to the model in order to predict their impact on the overall hydrologic conditions of the area.

The primary objective of the proposed project is to reduce the rate of loss of emergent wetlands. Reduction in the loss of these wetlands will be accomplished by lowering salinity and reducing water level fluctuations within the project area. To help achieve this primary goal, spoil bank maintenance, earth plugs, and several hydraulic structures are proposed within the project area. The proposed structures will be non-mechanical and will operate based on the differential water level across each structure. Descriptions and locations of the proposed project features are identified in Section 1.3, entitled “Project Description.”

## 1.2 ANALYSIS APPROACH

Numerical modeling has been used extensively to aid engineers and scientists with the study of many complex engineering, environmental, and ecological problems. In order to accurately model the complex hydrologic conditions of this area, the H3D three-dimensional numerical model was used to perform the analysis and evaluation for this project. Results of the numerical model will allow the agencies to make informed decisions about the most effective design and location of proposed project features.

The first step into the process was to calibrate and validate the numerical model against actual raw field measurements of water level and salinity. Upon obtaining satisfactory calibration and validation of the model, a comparison of “existing conditions” and “with project” features was performed. Project features were analyzed under numerous flow conditions as described later in this section. The output information from the model can be viewed as water level and salinity time series plots at selected locations within the project area, spatial and temporal variation animations, and spatial contour maps.

As outlined in the original scope of services, Table 1 below describes the original model scenarios proposed by both LDNR and NRCS.

**Table 1.1**

<b>Scenario Number</b>	<b>Scenario Description</b>
1	Existing Conditions
2	Existing Conditions / With Siphon (1,000 cubic feet per second)
3	Existing Conditions / Without Siphon
4	With Project / With Siphon (1,000 cubic feet per second)
5	With Project / Without Siphon

It was determined between all agencies and CHF that data from the year 2000 would be used as the simulation time period. For scenarios 2 and 4 shown above in Table 1.1, the siphon operation was set to run continuously with a discharge of 1,000 c.f.s. for the

six-month period of January 2000 through June 2000. The remaining six months, July 2000 through December 2000, were modeled without the freshwater discharge from the siphon. The simulations listed in Table 1.1 were originally performed with the bank lines of Bayou Grand Chenier set at a constant elevation of +2.5' (NAVD 88).

The design of the proposed project structures was later adjusted to narrow the cross sectional opening at each structure location. Details of the dimensions of these structures will be described later in the report. Additionally, the bank lines of Bayou Grand Chenier were surveyed and incorporated in the bathymetry files of the numerical model. After the incorporation of these adjustments to the model, two additional simulations for the time period of July 2001 to June 2002 were performed, namely "existing conditions" and "with project" conditions. The actual discharge measurements for the siphon were used in the July 2001 to June 2002 simulations.

It is recommended that when reviewing this report for the determination of the effects of the proposed features, special attention should be directed towards the results of modeling runs described in section 4.2. These model runs depict actual siphon flows, reduction of cross sectional openings of the project features, and actual bank line elevations along Bayou Grand Chenier as surveyed in the field. Graphs depicting "with project" and "without project" salinities and water levels are presented in figures 4.44 through 4.51. These graphs depict the water level and salinity changes that could be expected as a result of constructing the proposed project features.

### **1.3 PROJECT DESCRIPTION**

#### **Original Design:**

The original proposed project components as defined in the project scope of services are described below and are shown in Figure 1.4.

?? **Structure A:** Proposed fixed weir with barge bay to be located in Grand Bayou. Location of structure A is shown in Figure 1.5. The weir will be 340 feet wide and 14 feet deep at its deepest point. The weir will have a wing wall on each end, each protruding approximately 35 feet into the channel. The weir will have a crest elevation of 1 foot below marsh level. The barge bay will be 70' wide and the depth will be approximately 8 feet below mean low water.

?? **Structure B:** Proposed fixed weir with boat bay to be located in Jefferson Canal. Location of structure B is shown in Figure 1.6. The weir will be 170 feet wide and 13 feet deep at its deepest point. The weir will have a wing wall on each end, each protruding approximately 20 feet into the canal. The weir will have a crest elevation of 1 foot below marsh level. The boat bay will be 40' wide and the depth will be approximately 5 feet below mean low water.

- ?? Structure C: Proposed fixed weir with boat bay to be located in Stephan Bayou. Location of structure A is shown in Figure 1.7. The weir will be 82 feet wide and 8 feet deep at its deepest point. The weir will have a wing wall on each end, each protruding approximately 10 feet into the canal. The weir will have a crest elevation of 1 foot below marsh level. The boat bay will be 20' wide and the depth will be approximately 5 feet below mean low water.
- ?? Plug D: Earth Plug in existing channel (110 feet wide by 9.2 feet deep). Location of plug D is shown in Figure 1.6.
- ?? Plug E: Earth Plug in existing channel (153 feet wide by 3.5 feet deep). Location of plug E is shown in Figure 1.5.
- ?? Plug F: Earth Plug in existing channel (169 feet wide by 8.0 feet deep). Location of plug F is shown in Figure 1.5.
- ?? Approximately 10,000 linear feet of spoil bank maintenance on the northern spoil bank of the Tennessee Gas Pipeline Canal, from Bayou Grand Chenier eastward to the hurricane protection levee.

Figures 1.8, 1.9, and 1.10 show a proposed sketch of the proposed rock weir structures at locations A, B, and C, respectively.



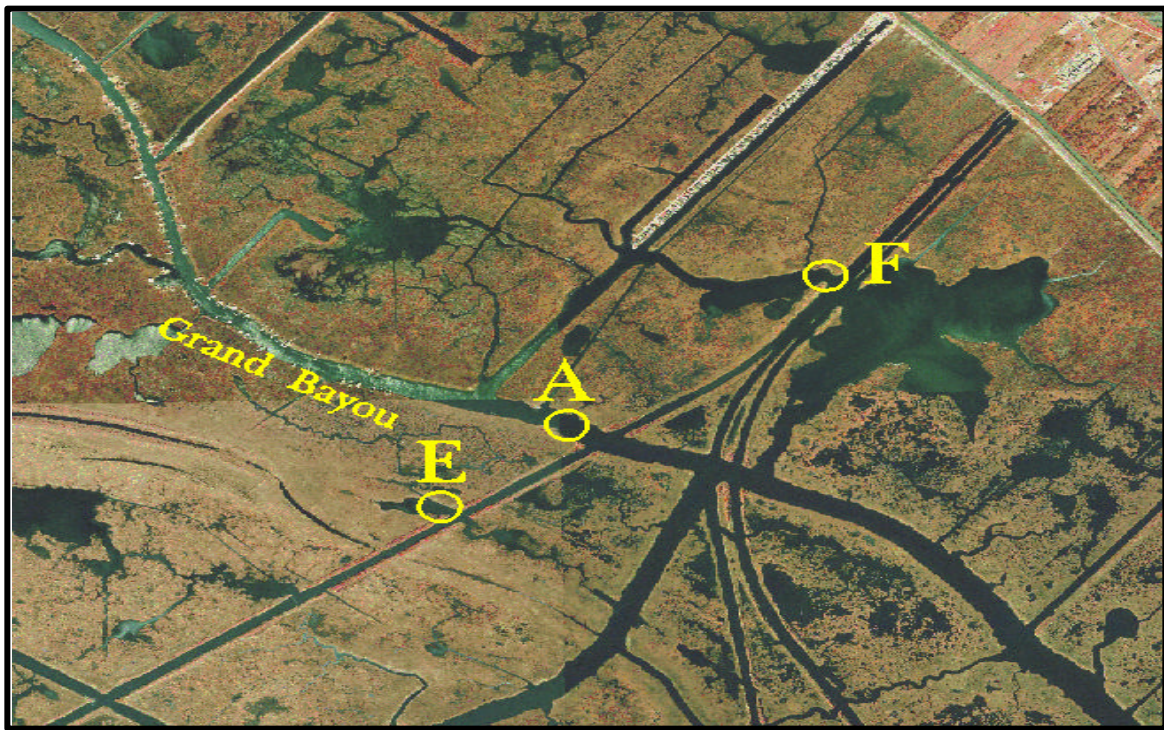
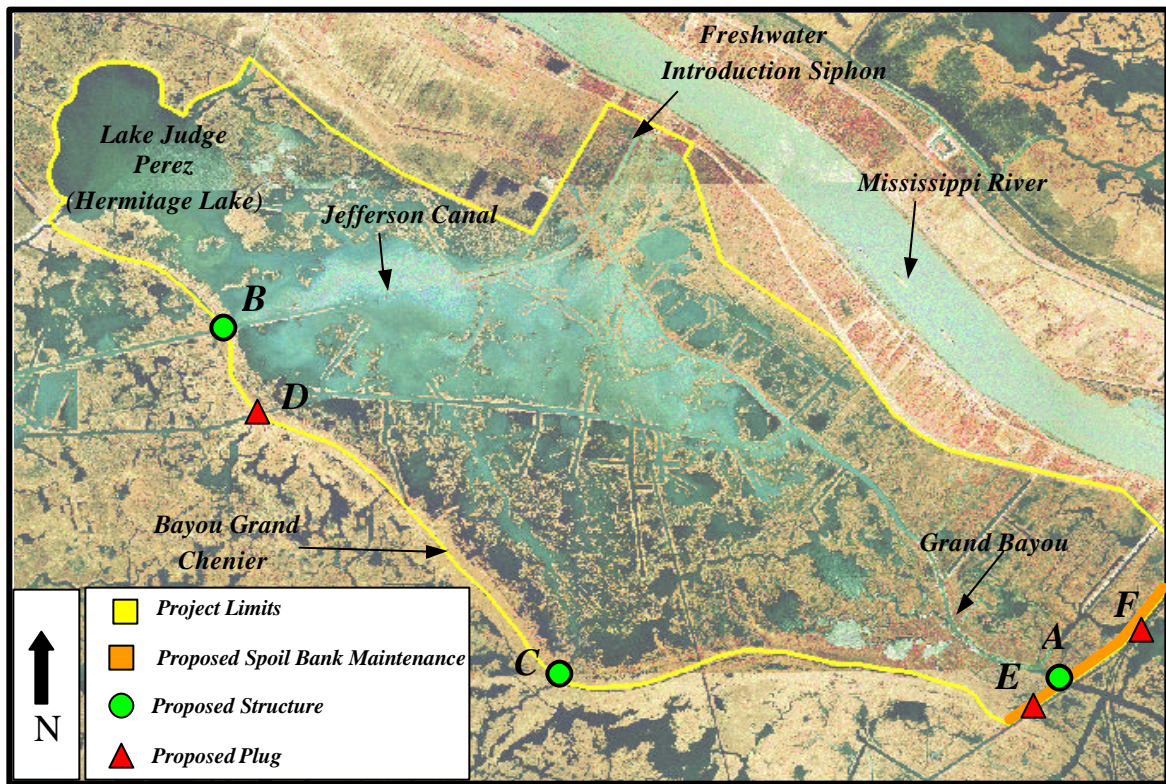






Figure 1.6: Locations of Proposed Structures B and D

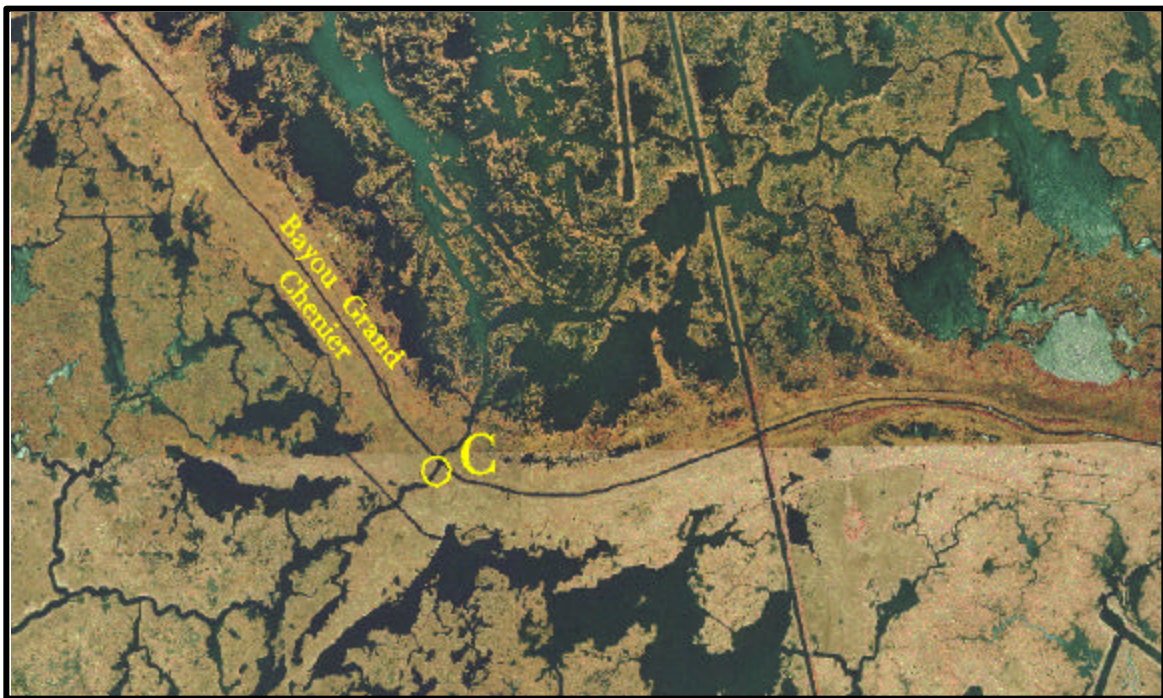


Figure 1.7: Location of Proposed Structure C



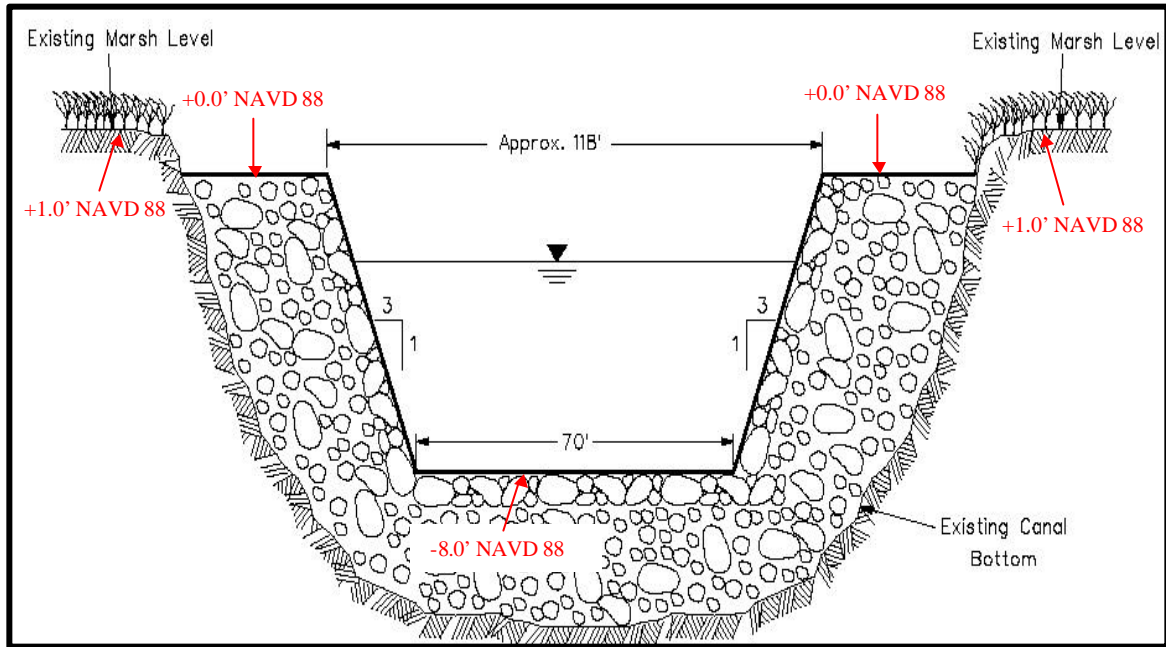


Figure 1.8: Original Proposed Structure Cross-Section at Location "A"

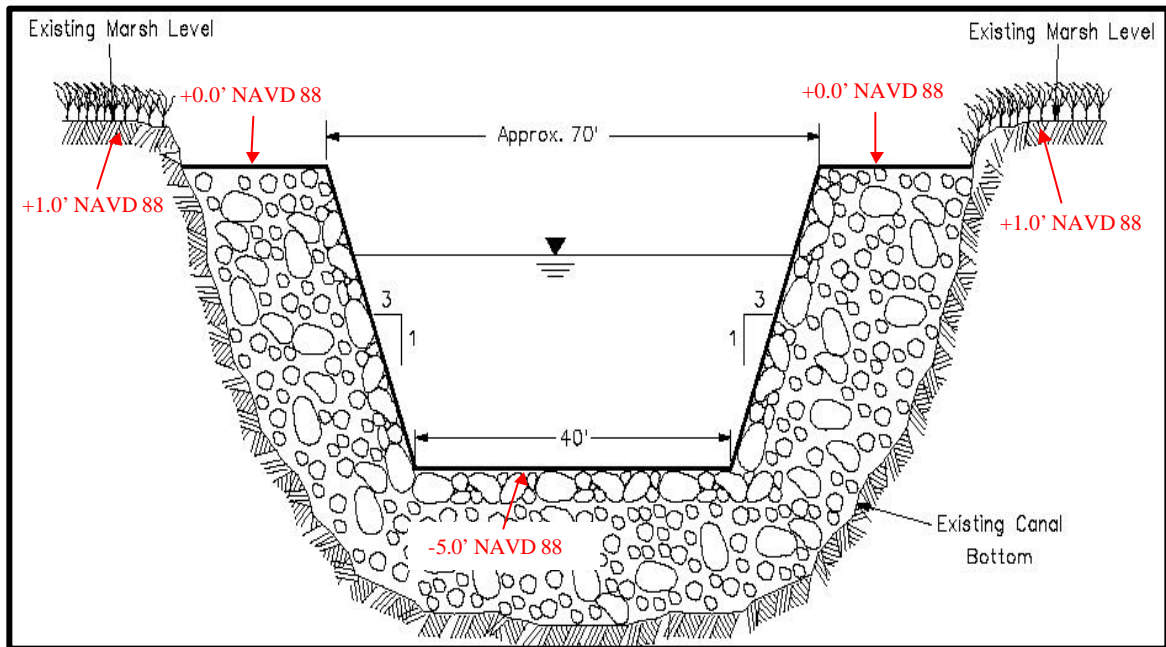


Figure 1.9: Original Proposed Structure Cross-Section at Location "B"

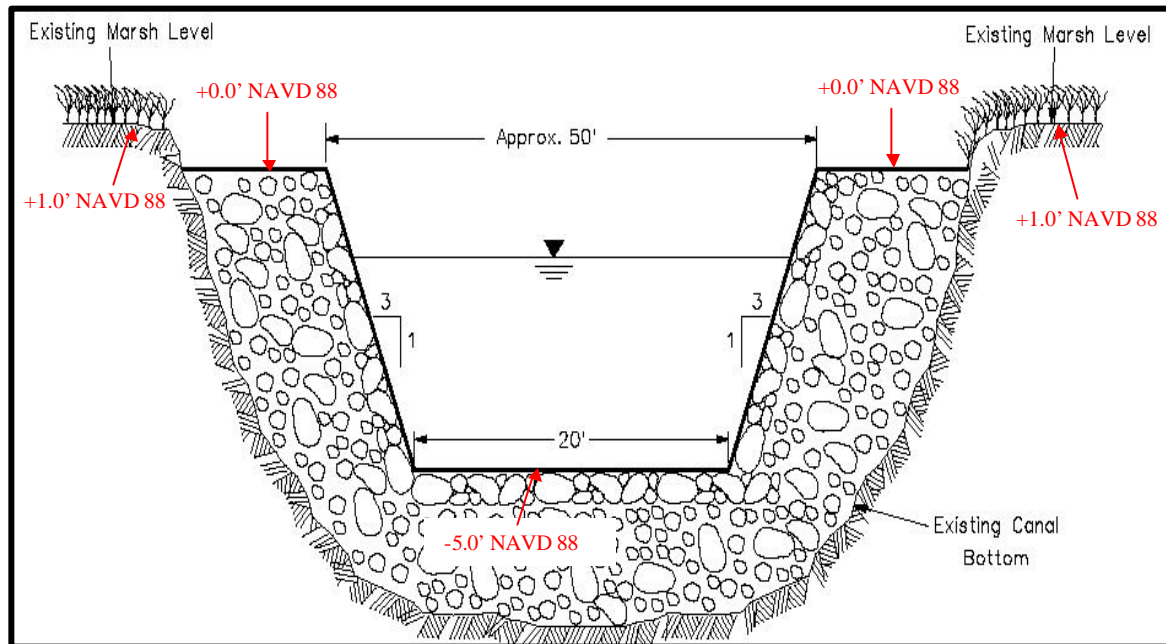


Figure 1.10: Original Proposed Structure Cross-Section at Location "C"

### **Revised Design:**

Based on the model results for the year 2000, the agencies agreed to adjust the design of the structures A and B (Directive sent on November 15, 2002 via email by LDNR). The revised designs are illustrated below in Figures 1.11 and 1.12.

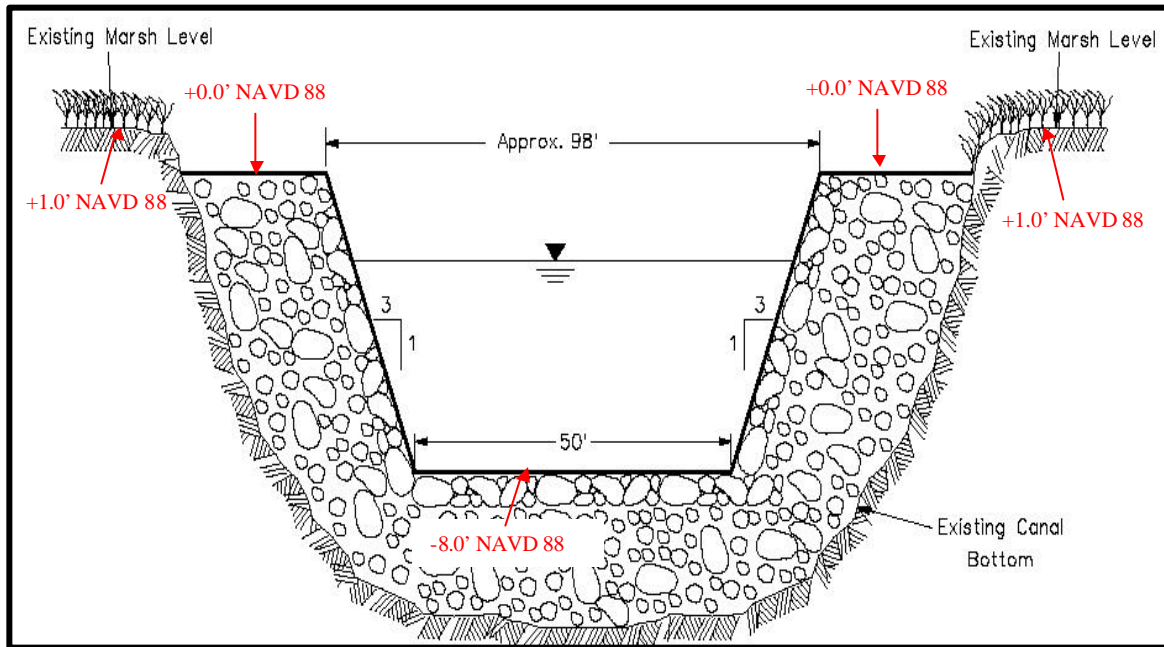


Figure 1.11: Revised Proposed Structure Cross-Section at Location "A"

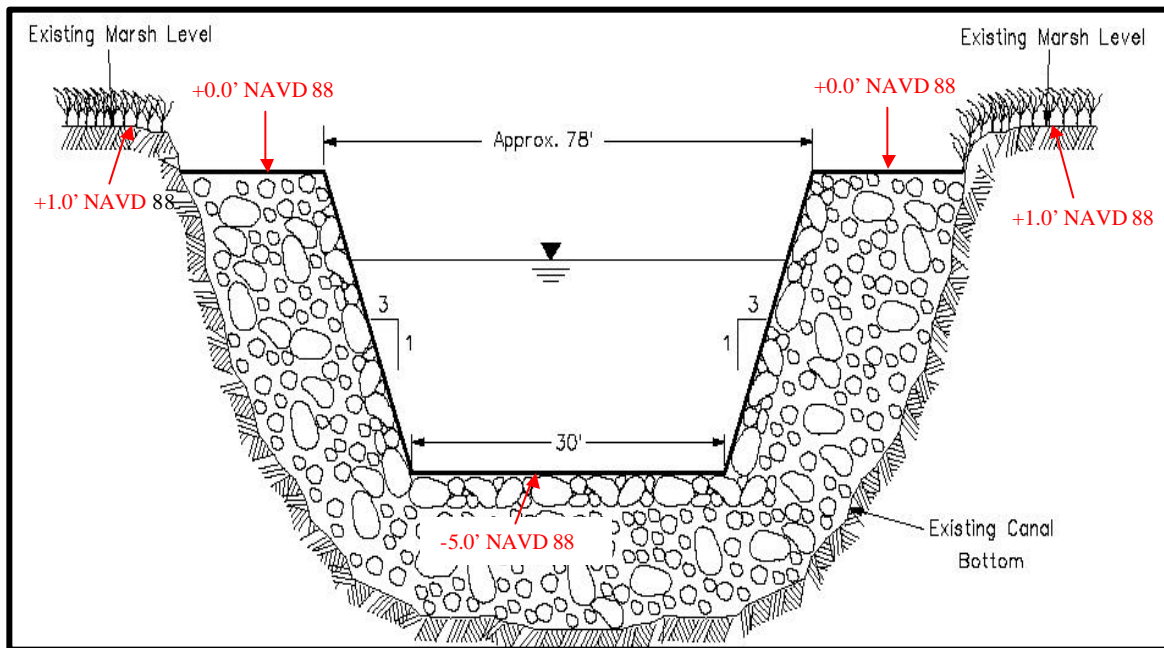


Figure 1.12: Revised Proposed Structure Cross-Section at Location "B"

## II. CHAPTER TWO

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### 2.1 MODEL SELECTION

The first step in performing a study of this type is to select the appropriate model that is capable of capturing the hydrologic characteristics of the project area. The following types of models are available:

- ?? One-dimensional (1-D) models
- ?? Two-dimensional (2-D) (depth averaged) models
- ?? Two-dimensional (2-D) (width averaged) models
- ?? Quasi three-dimensional (3-D) models
- ?? Three-dimensional (3-D) models

There are distinct differences in the approach and capabilities among these model types. In one-dimensional models, flow parameters (i.e. velocity, salinity, etc.) are averaged over the cross-sectional area, while in two-dimensional models these parameters are averaged over the water depth or width. Three-dimensional models do not average the flow parameters in any spatial direction. Three-dimensional models calculate parameters along the longitudinal, vertical, and transverse axes and can be used to model bed shear due to wind-induced currents.

The primary objective of this project is to reduce the rate of loss of emergent wetlands by lowering salinity and reducing water level fluctuations within the project area. In determining the suitable model for the project, the following issues were taken into consideration:

- ?? The majority of water movement throughout the project area occurs within large water bodies (i.e. lakes, inundated marsh, etc.) and shallow sheet flow movement.
- ?? The water exchange between lakes occurs mainly through broken marsh and defined channels.
- ?? The salinity and water level in the project area changes not only seasonally but also daily and hourly.
- ?? The proposed hydraulic structures are expected to impact the surrounding water level and salinity patterns. The model should determine the extent of that impact.
- ?? The model should be computationally efficient, should have the ability to model “wetting” and “drying” effects, and should have been previously applied to similar projects and showed reliable predictive capabilities.



Utilizing a one-dimensional model would not capture the effects of current and salinity circulation within the lakes. Additionally a one-dimensional model will not accurately represent water and salinity fluctuations throughout the marsh as a result of shallow sheet flow.

Two-dimensional models are applicable to the simulation of hydraulic related phenomena in lakes, estuaries, bays, coastal areas and seas where stratification can be neglected. A two-dimensional model could not have been used since it was determined that the model domain would extend to Barataria Bay, which contains salinity stratification.

Three-dimensional models take into account density variations (stratification). Since the model domain extends to Barataria Bay (as shown in Figure 2.24), which has density variations throughout the water column, the model selected should provide detailed information about the flow velocity and salinity for both the horizontal plane and the water column. Accordingly, a three-dimensional model was used in order to properly simulate the hydrologic conditions that affect this project area.

There are several three-dimensional numerical models commercially available. The differences between commonly accepted modeling packages are primarily their individual ability to adequately model hydraulic structures, pre-and post-processing capabilities, ability to customize the code to the current application, and cost. After reviewing the capabilities and cost of various three-dimensional modeling packages, it was determined that the three-dimensional model, H3D, would be the model of choice that would best fit the project scope.

H3D is a three-dimensional circulation model. The model is a modification to an earlier version called the GF8 model, which represents the eighth in a series of models described in Crean et al, 1988a<sup>1</sup> and Crean et al, 1988b<sup>2</sup>. It computes the three components of velocity ( $V_x$ ,  $V_y$ ,  $V_z$ ) as well as scalar quantities, such as salinity, temperature, and contaminant concentrations on a Cartesian three-dimensional grid. The current version of the model is described in detail in Stronach et al. (1993)<sup>3</sup>. The model solves a version of Navier Stokes equations of motion, with the turbulent fluxes expressed in an eddy viscosity/diffusivity formulation. It uses a shear-dependent turbulence formulation in the horizontal direction, and a shear and stratification dependent formulation in the vertical direction. The numerical model includes provisions for wetting and drying, which is an important consideration for the shallow marshland within the project area. Flooding and drying is implemented in a straightforward manner, and care is taken to ensure that scalar quantities, such as salinity or contaminants, are conserved in the wetting and drying processes. The model is semi-

<sup>1</sup> Crean, P.B., Murty, T.S. & Stronach, J.A., 1988a. Mathematical Modeling of Tides and Estuarine Circulation. Springer-Verlag, New York, 471 pp.

<sup>2</sup> Crean, P.B., Murty, T.S. & Stronach, J.A., 1988b. Numerical simulations of oceanographic processes in the waters between Vancouver Island and the mainland. *Oceanography and Marine Biology: An Annual Review*, 26, 11-42.

<sup>3</sup> Stronach, J.A., Backhaus, J.O., & Murty, T.S., 1993. An update on the numerical simulation of the waters between Vancouver Island and the mainland: the GF8 model. *Oceanography and Marine Biology Annual Review*. 31, 1-86.

implicit, so that relatively large time steps can be used. It is fully unsteady (i.e. changes in wind speed and direction, water levels, and salinity fluctuations are taken into account). The model also has the capability to model hydraulic structures. The model provides detailed information about flow velocities, salinity levels, and water depth.

Previous applications of H3D include projects both within the State of Louisiana and outside of the United States of America. Within Louisiana, H3D has been used on two coastal modeling projects, namely, the Brown Lake Restoration Project (CS-09) and the Hydrodynamic and Salinity Modeling of the Calcasieu-Sabine Basin Project. Outside of the United States of America, H3D has been extensively used in Canada (Strait of Georgia, Juan de Fuca Strait, and Puget Sound), and has been reported in Stronach et. al, 1993<sup>3</sup> as a model that is a “reliable and accurate baroclinic model for coastal water bodies, and its use for engineering and scientific studies is both justified and highly recommended.” For more information about the above referenced numerical model simulation projects please refer to Stronach et al, 1993<sup>3</sup>, Meselhe et al, 2002<sup>4</sup>, and Meselhe et. al, 2001<sup>5</sup>.

### **2.1.1 MODEL RESOLUTION**

The model grid resolution is an important factor that affects the model’s ability to resolve the spatial variability of the flow characteristics. Typically, a grid refinement exercise needs to be performed in order to determine the optimum grid size for each application. Sometimes in practical applications, the grid has to be finer than the optimum grid size in order to capture particular features of importance. In the project discussed here, the grid resolution is 50 meters (approximately 164 ft) in both directions of the horizontal plane. The grid size was selected such that it can capture the channels within and near the project area. This grid size is finer than the size needed to resolve the circulation pattern in and near the project area. In the horizontal plane, the grid has 300 nodes in the north-south direction and 440 nodes in the east-west direction, and has 10 nodes over the vertical plane (water column).

## **2.2 DATA COLLECTION & REVIEW**

### **2.2.1 BATHYMETRIC AND TOPOGRAPHIC DATA**

The accuracy of the results of any numerical model is directly impacted by the accuracy of the bathymetric data. For two and three-dimensional numerical models, bathymetric information is required in the form of bare earth spot elevations within all open water areas, canals, and marshes within the model domain. The information used to generate the bathymetry file include:

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<sup>4</sup> Meselhe, E.A., and Dax Douet. Hydrodynamic Modeling of the Brown Lake Restoration Project (CS-09), report submitted to Louisiana Department of Natural Resources, Coastal Restoration Division.

<sup>5</sup> Meselhe, E.A, and Noshi, H., 2001. Hydrodynamic and salinity modeling of the Calcasieu-Sabine basin. Final report submitted to Louisiana Department of Natural Resources, Coastal Restoration Division.

- ?? Spot elevations of the bottom of open water bodies, canals, and open marshes
- ?? Spot elevations of all significant hydrologic barriers or features (i.e. levees, ridges, etc.)

Prior to any field survey data collection, time was spent searching for existing surveys that may have been performed recently within the model domain. Contacts were made to LDNR, NRCS, National Oceanic and Atmospheric Administration (NOAA), and the United States Geological Survey (USGS). No information was found pertaining to bathymetry with the exception of digital NOAA Nautical Maps. It was later determined that a field survey must be performed to collect the necessary input bathymetry for the numerical model. After review of 1988 Digital Orthogonal Quarter Quadrangles (DOQQ) aerial photography, locations for spot elevations were carefully selected. These survey locations were selected such that the survey can both represent the model domain (approximately 105,000 acres), and be performed within the allocated budget.

In order to gather survey data for the pre-selected spot elevation locations, one initial control point would be needed at the project area. Further control was then set using a combination of Fast-Static and Real Time Kinematic Global Positioning System (RTK GPS) techniques. The project monument selected was an existing National Geodetic Survey (NGS) tidal benchmark. The station name was “876 1602 C TIDAL”. Various factors contributed to the selection of this point. NGS reported the site as being suitable for satellite observations and it had a stability classification of ‘B’ (holds position/elevation well). The benchmark consisted of a brass disc set on a 22-meter stainless steel rod. The control points used were those previously observed in the LDNR-South Louisiana Coastal Wetlands Primary GPS Network (Reggio 2, Lafitte 2, and 876 1724 C TIDAL). Figure 2.1 illustrates the location of these monuments (Primary LDNR Monuments).

On March 19, 2001 a four-man crew equipped with Trimble 4000 dual-frequency GPS receivers were dispatched to the four control points. Simultaneous observations were made throughout the day for a total of five separate sessions. The average session lasted 90 minutes. Fixed height tripods with L1-L2 antennas and ground planes were used on all points except for “876 1724 C TIDAL” which was too close to a chain-link fence, so the antenna was set on a standard tripod. On March 20, 2001, additional site control was set and checked using both Fast-Static and RTK methods. Three temporary control points were set at the site using ¾” iron pipes that were four feet long. These control points were set at strategic locations to establish RTK radio communications throughout the project area.

Beginning on March 20, 2001 spot elevations were taken throughout the project area utilizing RTK GPS techniques. The base station coordinates used were those published on the NGS data sheet for the benchmark “876 1602 C TIDAL”. Spot elevation values were later post processed and adjusted in the office by a Registered Professional Land Surveyor in the State of Louisiana. The selected mode of transportation for the collection of field data was an airboat. Elevations were taken at pre-determined locations as depicted on an aerial

photograph. Collection of spot elevations continued for three days throughout the marsh, open water bodies, canals, and bayous.

All static data was processed with Trimble Geomatics Office software. Initially the International GPS Service (IGS) ultra-rapid ephemeris was used as opposed to the broadcast ephemeris. All GPS derived baseline solutions were fixed. Closure computations were made to expose problematic vectors. An independent network was then created with the best vectors found in the survey network. Initially, the monument “Lafitte 2” was held in the minimally constrained network. The network passed the chi-square test with a scalar of 4.29. Comparisons were made to the published horizontal values at the other occupied control points (no points differed by more than 0.05 feet). The Geoid99 model was then applied to all ellipsoidal heights to determine their orthometric heights. The final constraint was then made by holding the adjusted North American Datum of 1983 (NAD 83) (La. South Zone, US Survey Feet) and North American Vertical Datum of 1988 (NAVD 88) (US Survey feet) values for monuments “Reggio 2”, “Lafitte 2”, and “876 1724 C TIDAL” as provided by LDNR and shown in the South Louisiana Coastal Wetlands Primary GPS Network manual. The average loop closure reported was .0279 survey feet horizontal, -.0339 survey feet vertical, and .0178 parts per million. Once the position of monument “876 1602 C Tidal” was derived, then the project control and RTK data was imported and reduced by Trimble Geomatics software. The initial network was reprocessed on March 29, 2001 using a precise ephemeris, and the final coordinates were reported. Upon completion of post processing of all survey data shown in Figure 2.2, the data was then imported into Microstation (CAD program, by Bentley Systems, Inc.). The survey information was overlaid on the USGS DOQQ’s for the project area to commence the process of digitization and creation of a three-dimensional bathymetric grid map. The spot elevations taken in the field were used to guide the production of the three dimensional grid for the model. These elevations were used to assign elevation values to the land-water digitized interfaces as shown in figure 3.1. Spot elevations that were taken in water bottoms were used to assign elevation values to areas in the model that are shown to be water bodies, and spot elevations taken within the marsh areas were used to assign elevations in marsh areas within the model grid. It must be noted that these spot elevations were placed into the model grid at the exact same geo-referenced coordinates as the actual survey. The three-dimensional surface was used as the basis for the bathymetry input-file for the numerical model.



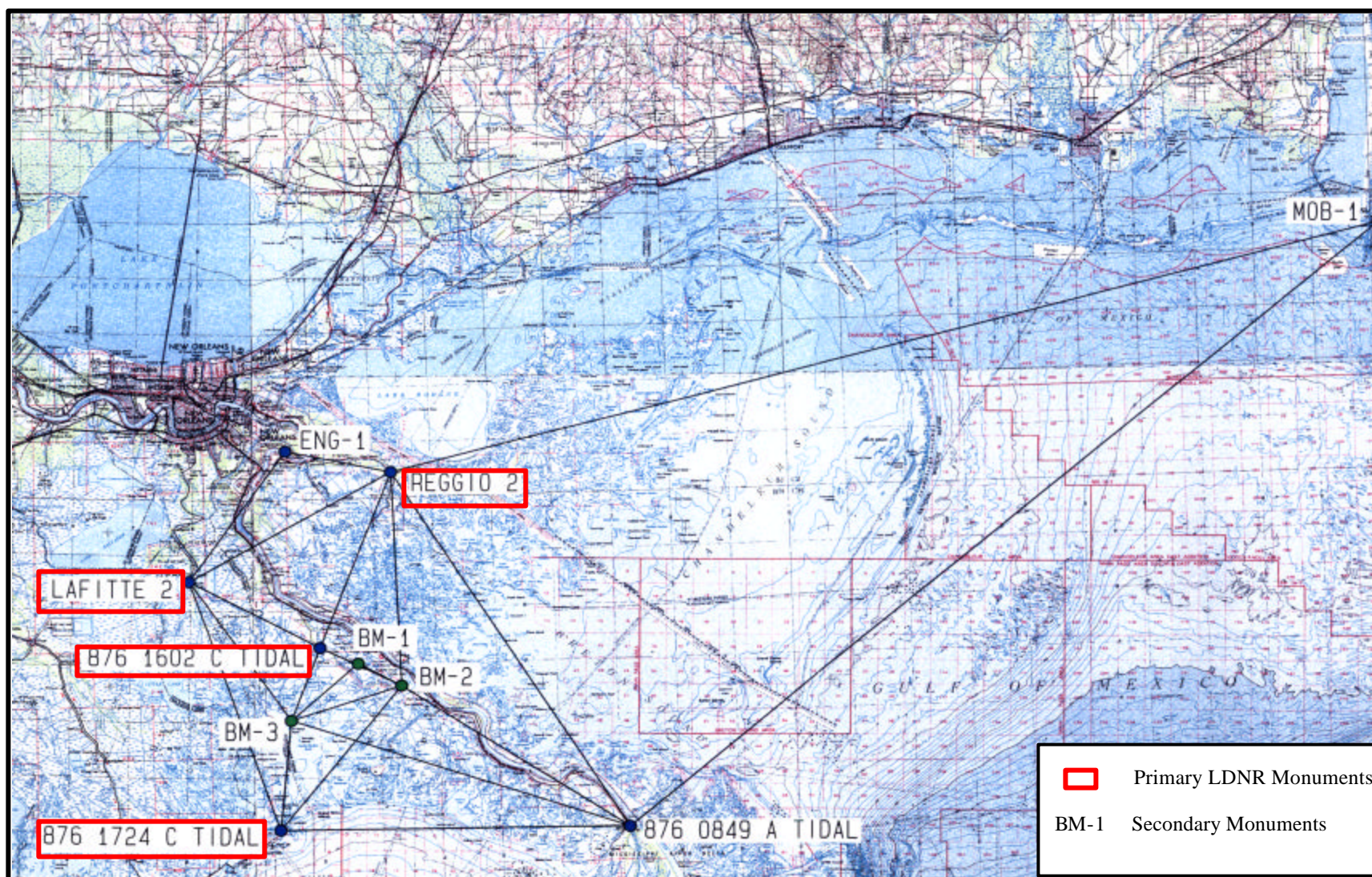


Figure 2.1: Basemap Showing Primary & Secondary Monumentation Used and Set In Collection of Bathymetric and Hydrologic Data







Upon completion of the initial spot elevation survey, it was later determined that the ridge along the banklines of Bayou Grand Chenier would need to be surveyed to determine its role as a possible hydrologic barrier within the model. It was recommended by CHF and approved by LDNR that both bankline ridges (interior and exterior) would be surveyed at 1,000-foot intervals for a total distance of approximately 60,000 linear feet (Figure 2.3). The survey crews were instructed to survey both ridges at 1,000 foot intervals along the centerline of Bayou Grand Chenier, take cross sections at all canal intersections along Bayou Grand Chenier, and to take spot elevations at any abnormally high or low points within the 1,000-foot intervals.

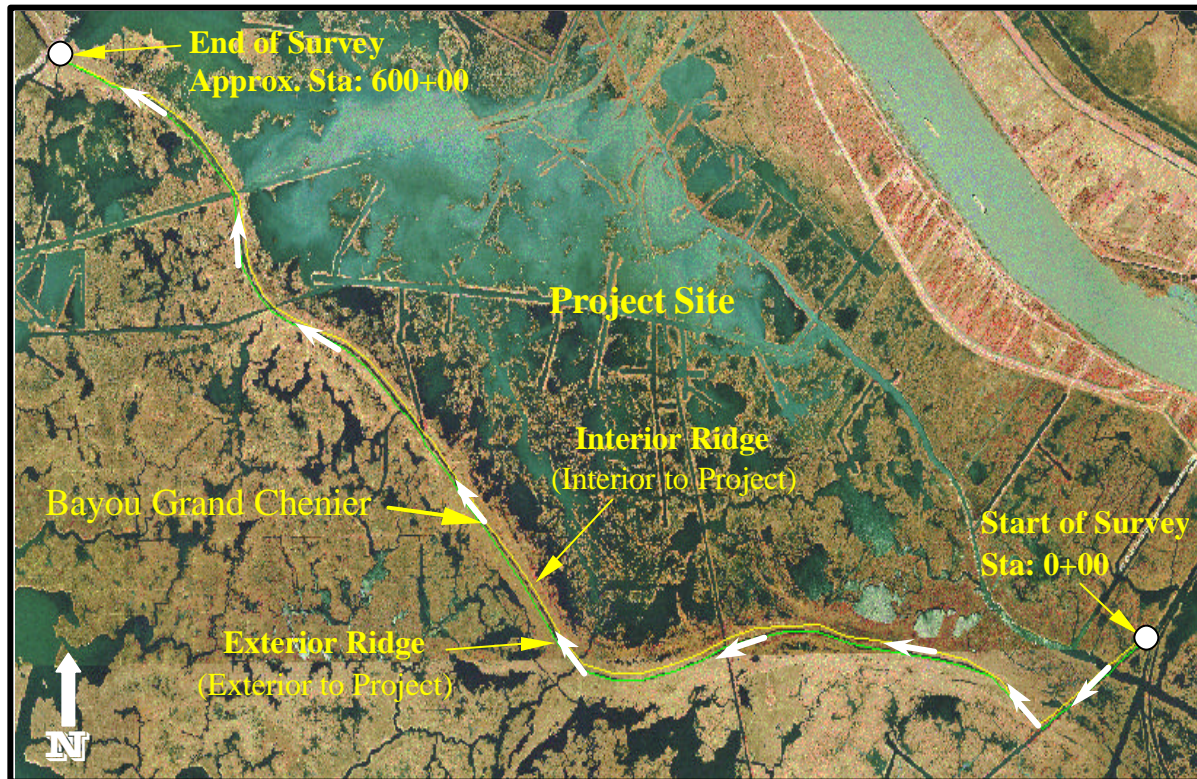


Figure 2.3: Survey Plan of Banklines Along Bayou Grand Chenier

On August 12, 2002, survey crews from CHF mobilized to Bayou Grand Chenier to commence a detailed topographic survey of the ridge along the banklines of Bayou Grand Chenier. This effort also included surveying cross sections at canal crossings with Bayou Grand Chenier. The surveyed cross-sections identified in Figure 2.8, are shown in Figures 2.9 through 2.23. The purpose of this effort was to ensure accuracy of the numerical model's representation of this potential hydrologic barrier. The survey itself lasted a total of three days, and was performed utilizing previously installed monumentation (as noted previously) and RTK GPS technology. Upon completion of the field survey of the Bayou Grand Chenier banklines, the data was used to revise the bathymetry input-file for the H3D modeling software. Prior to this survey, the three-dimensional grid surface had both banklines (interior and exterior) of Bayou Grand Chenier set at an estimated elevation of +2.5' NAVD 88 based on the recommendation and existing surveying notes of the Lafayette field office of NRCS.



The major features of the ridge were cross-referenced with geo-rectified 1988 DOQQ aerial photography to facilitate evaluation of the survey data (Figure 2.4). Namely, points 1 through 12 along the exterior ridge and points 13 through 25 along the interior ridge are shown in Figures 2.4, 2.5, and 2.6.

Figures 2.5 and 2.6 show the survey profile data for the exterior and interior ridges, respectively. The total surveyed length of each bank line is approximately 10.7 miles. According to the survey data, an average elevation for the bank lines is +1.07' NAVD88. That average is based on calculations that exclude the channels and the excessively high points (spoil banks, tree growth, etc. that are higher than + 2.0 NAVD88). The length of each bank line excluding channels and the excessively high points is approximately 9.4 miles.

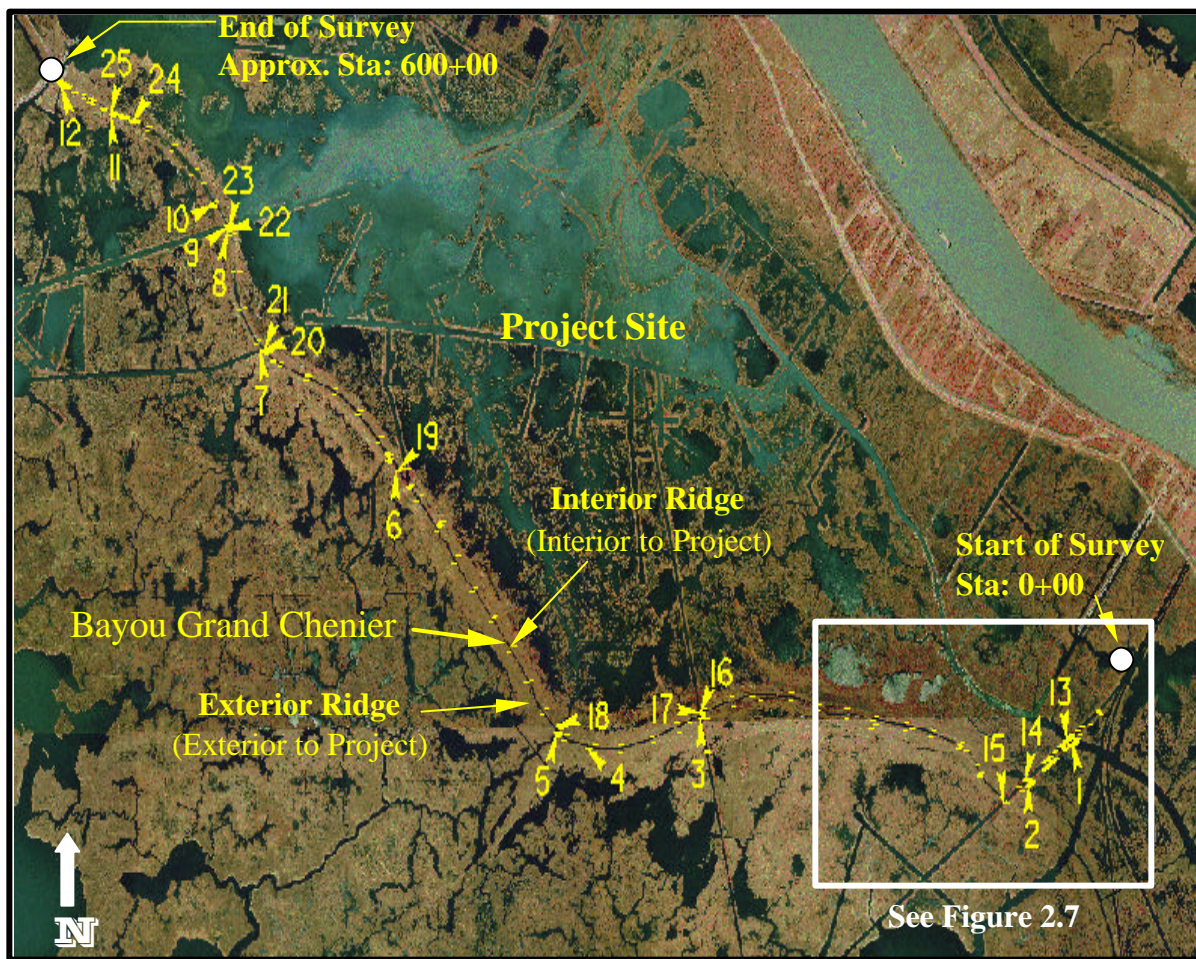


Figure 2.4: Final Survey of Bayou Grand Chenier Showing Locations of Survey and Points Along the Survey Showing Significant Features.

Figure 2.7 illustrates a recent aerial photograph of the area taken at low altitude along Bayou Grand Chenier. Reference points 1,2,13,14 and 15 shown in Figure 2.4 are also

highlighted in Figure 2.7 to give another perspective of the location of the survey along the bayou.

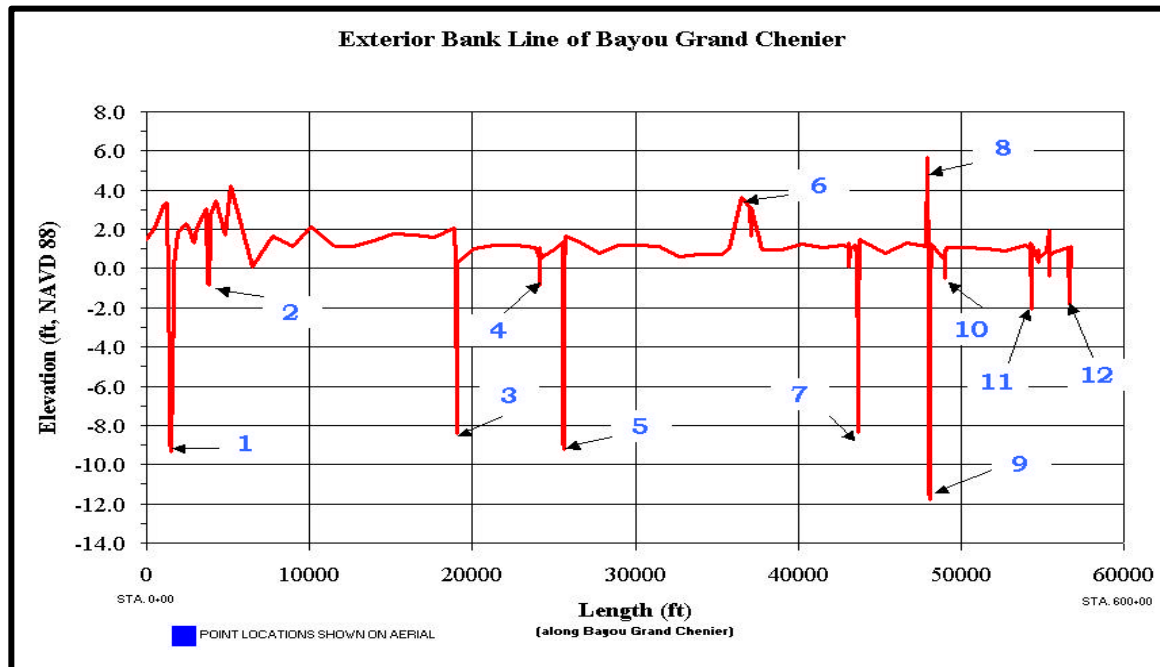


Figure 2.5: Survey Profile of the Exterior Ridge of Bayou Grand Chenier

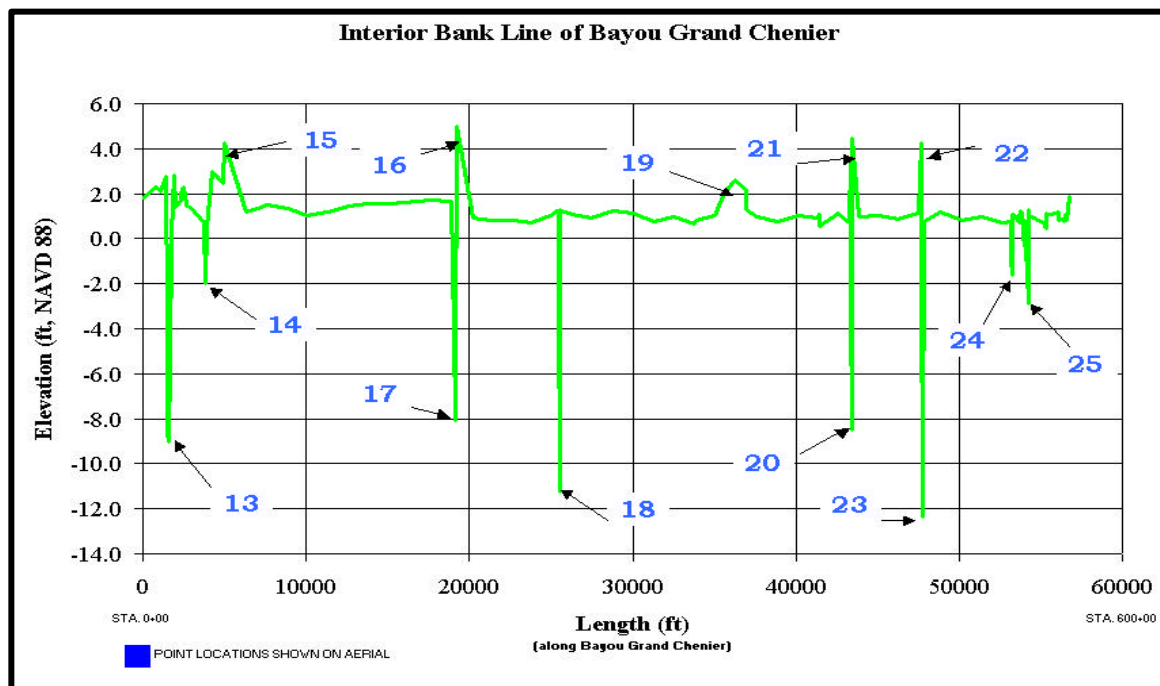


Figure 2.6: Survey Profile of the Interior Ridge of Bayou Grand Chenier



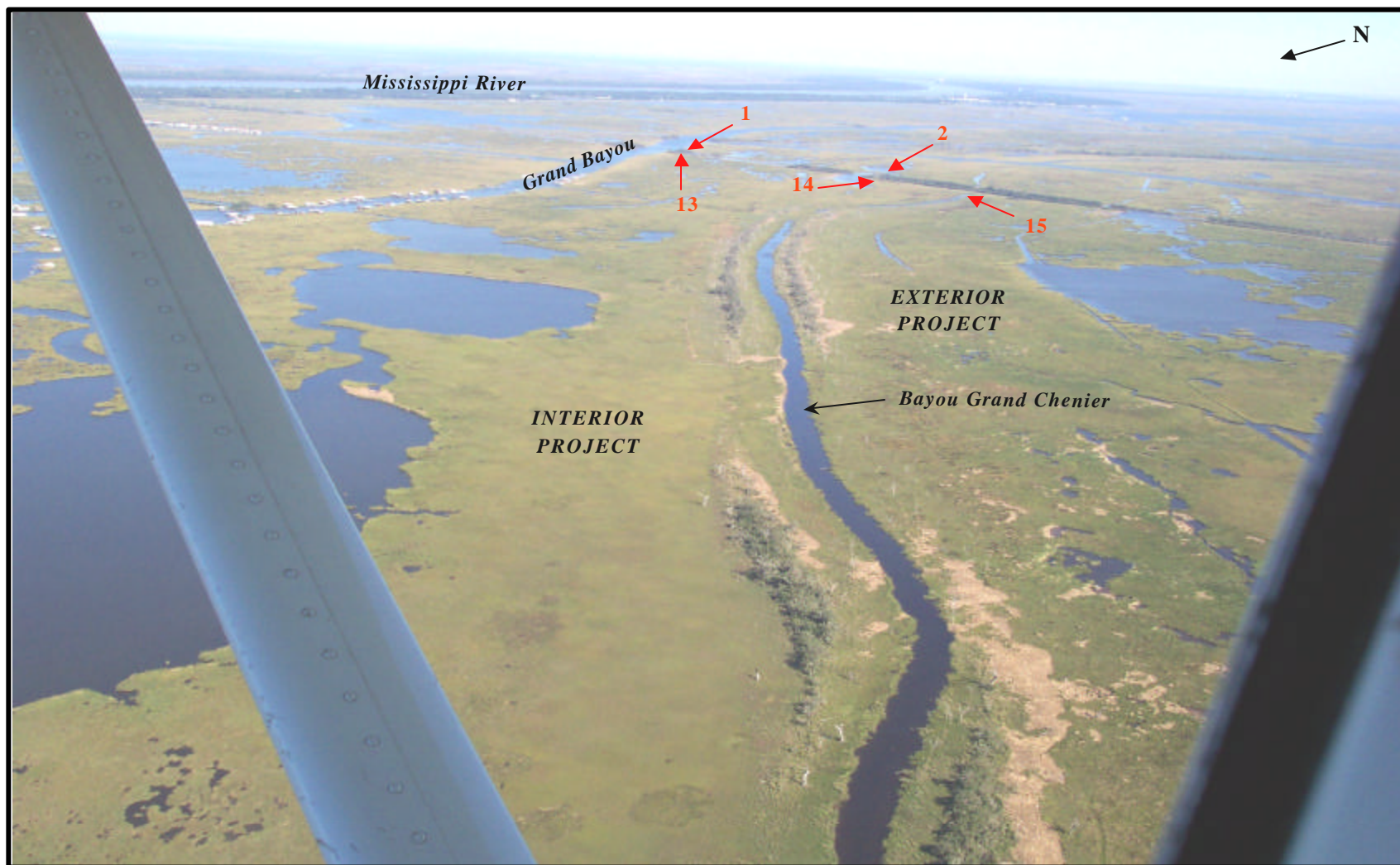


Figure 2.7: Low Altitude Photography of Bayou Grand Chenier Showing Points 1,2,13,14, and 15.





Figure 2.8: Location of Surveyed Cross Sections During Survey of the Bayou Grand Chenier Ridge (Refer To Figures 2.9 through 2.23 for Cross Section Data).

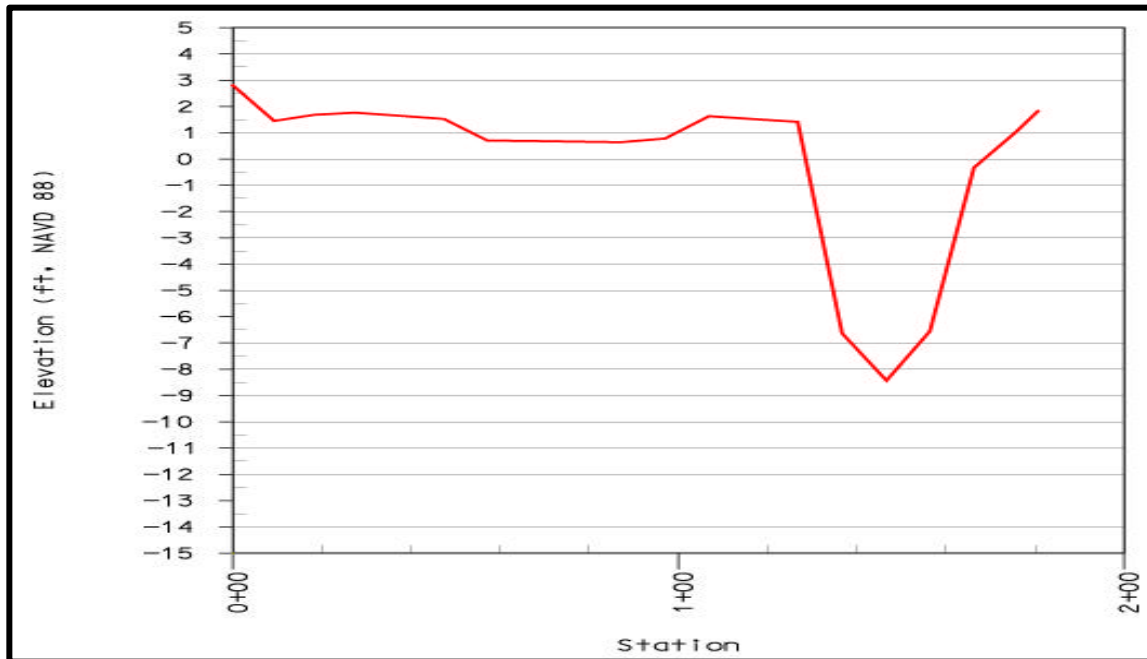


Figure 2.9: Cross Section A

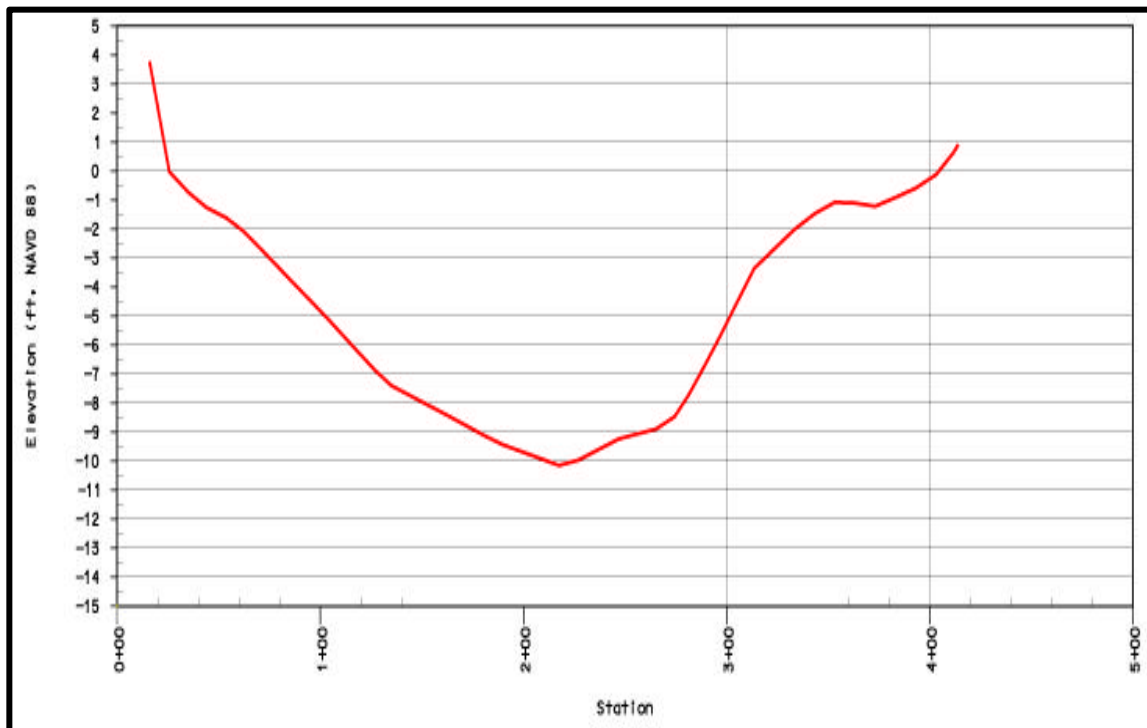


Figure 2.10: Cross Section B



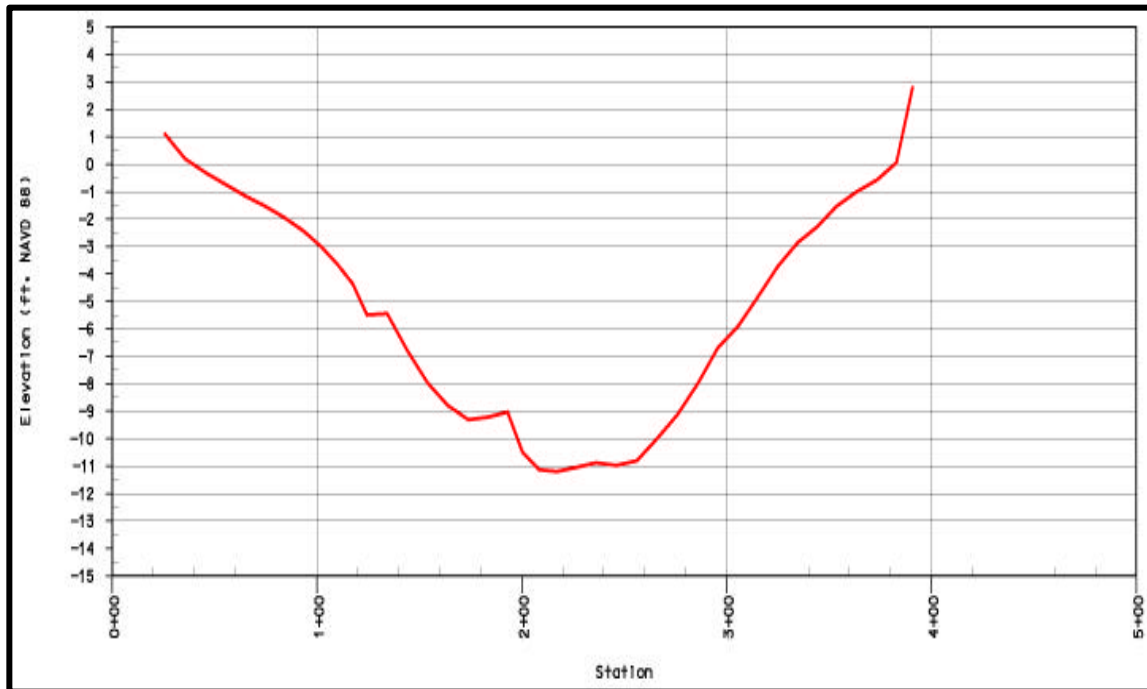


Figure 2.11: Cross Section C

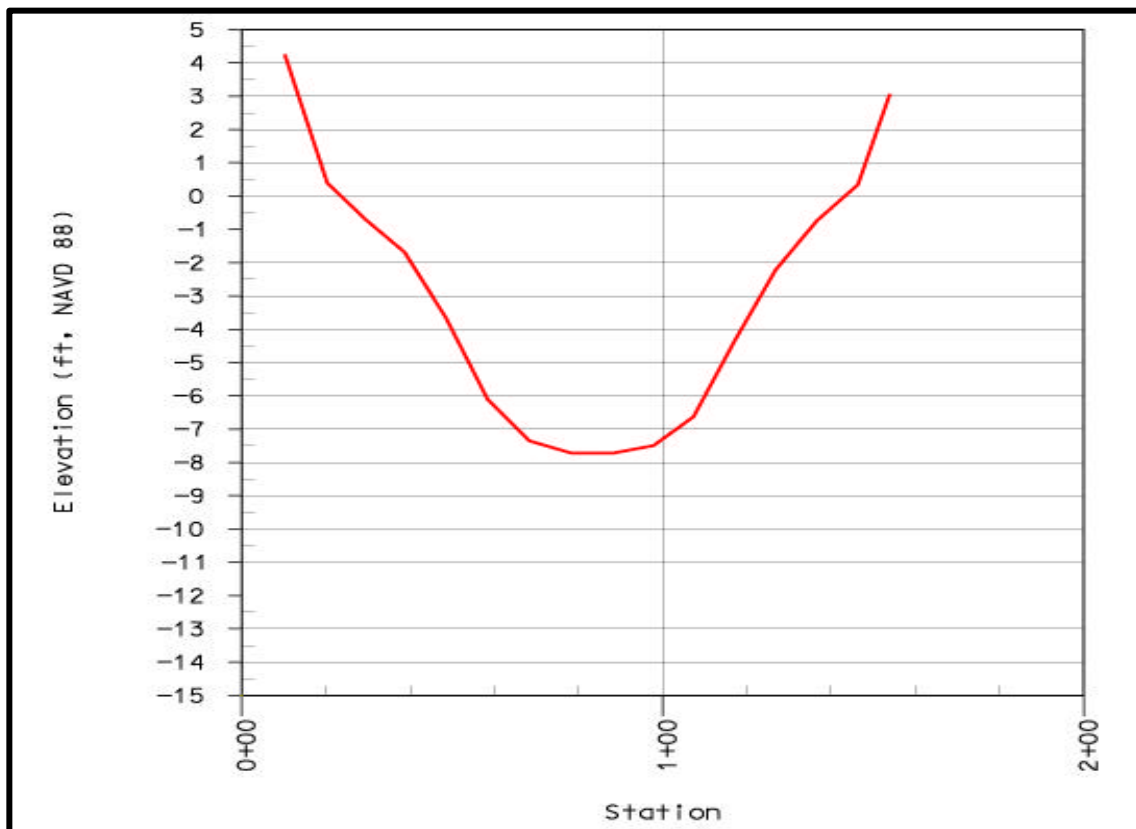


Figure 2.12: Cross Section D

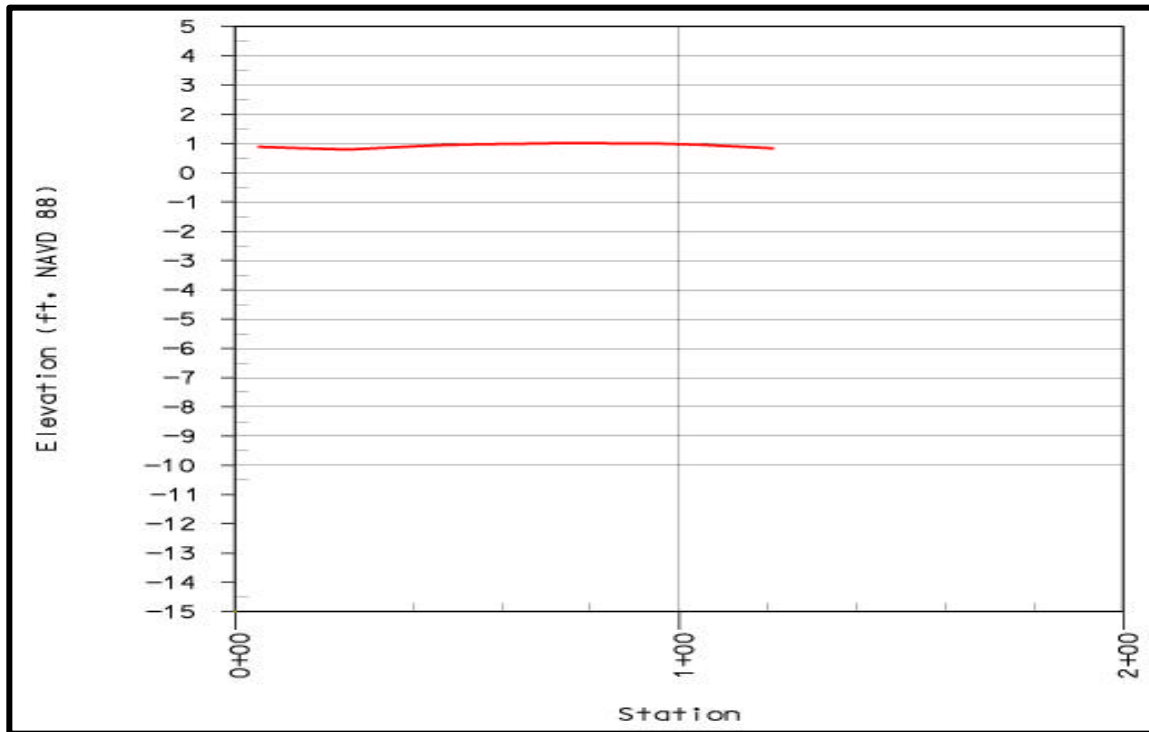


Figure 2.13: Cross Section E

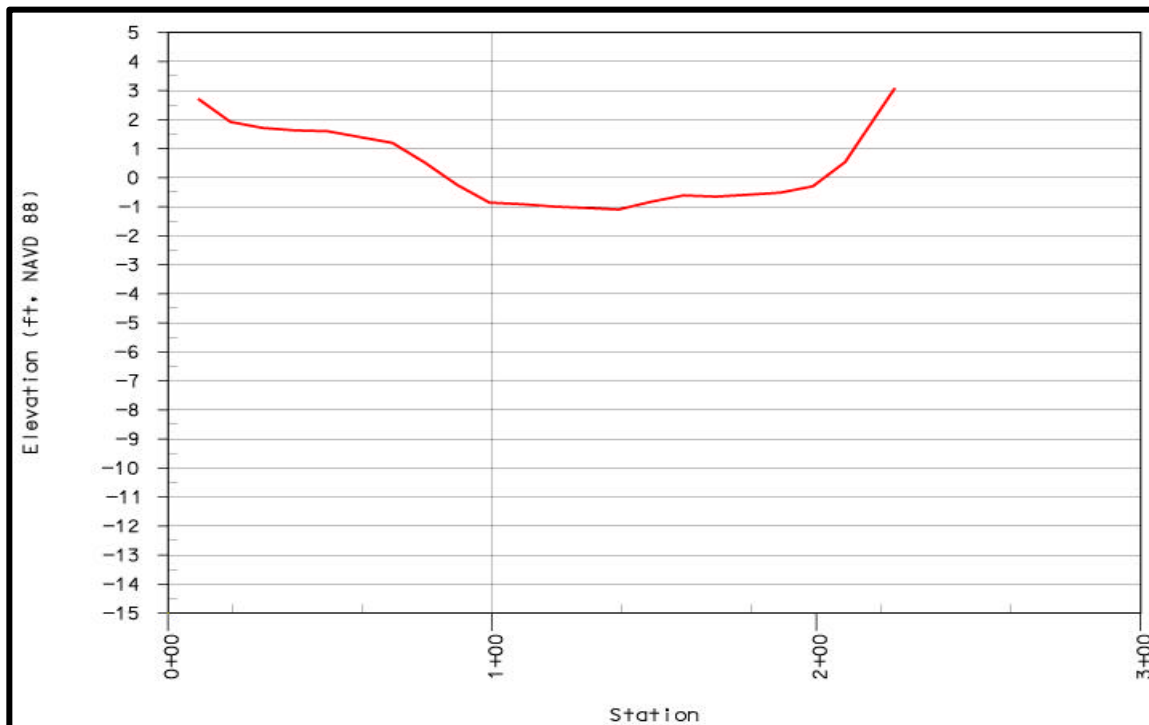


Figure 2.14: Cross Section F

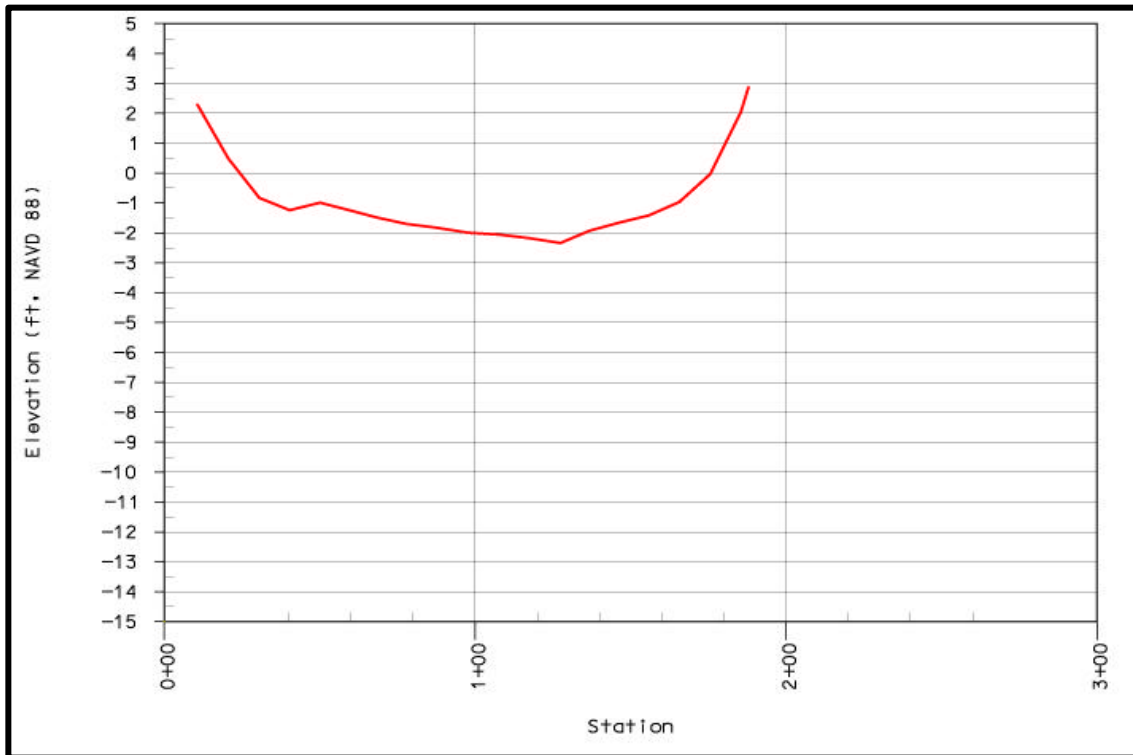


Figure 2.15: Cross Section G

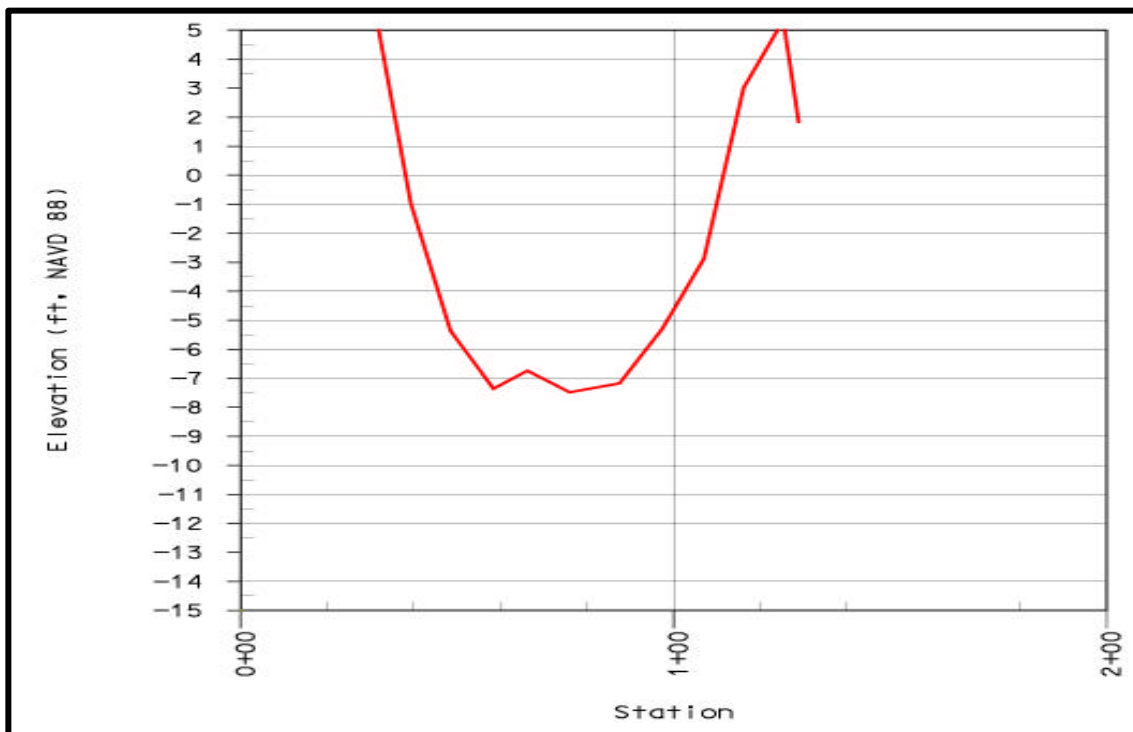


Figure 2.16: Cross Section H

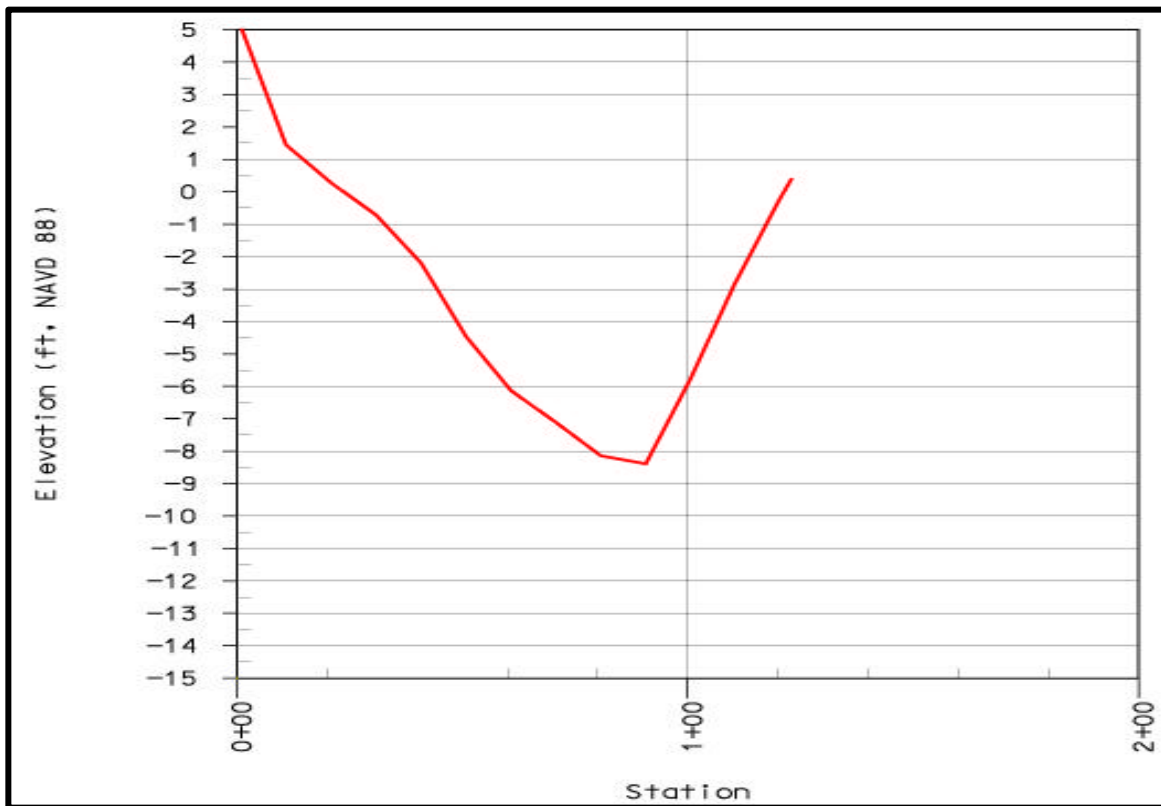


Figure 2.17: Cross Section I

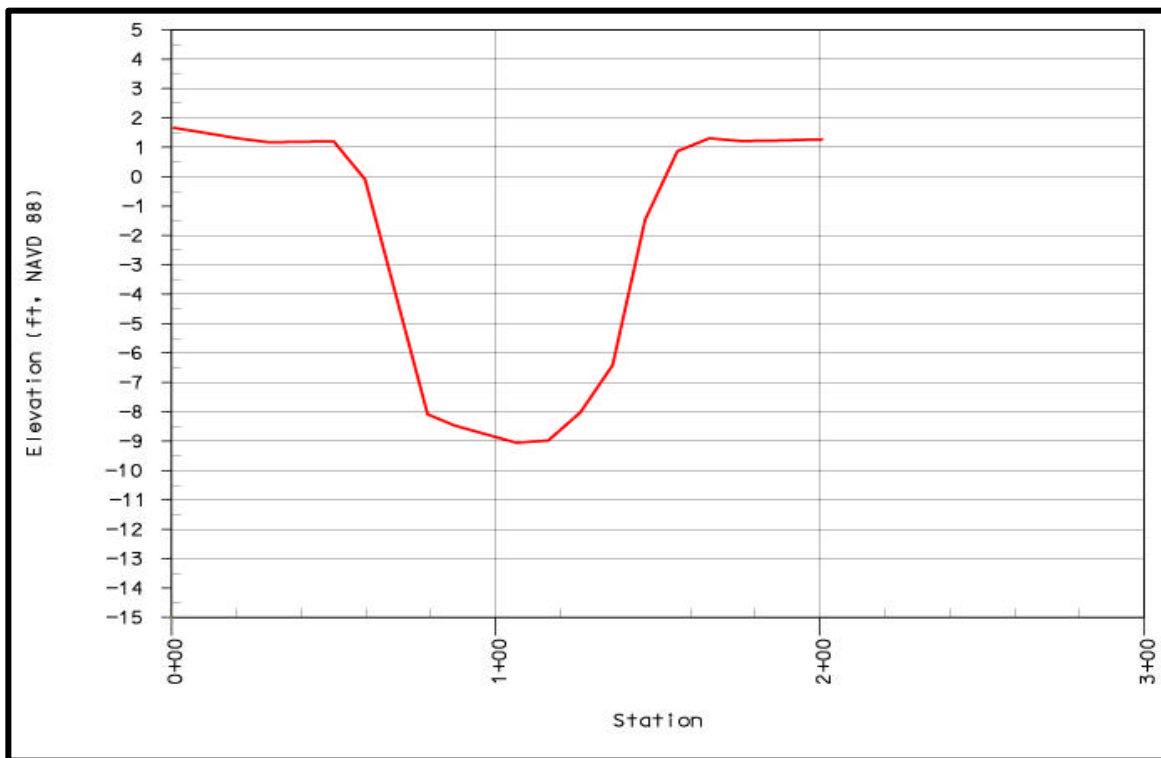


Figure 2.18: Cross Section J



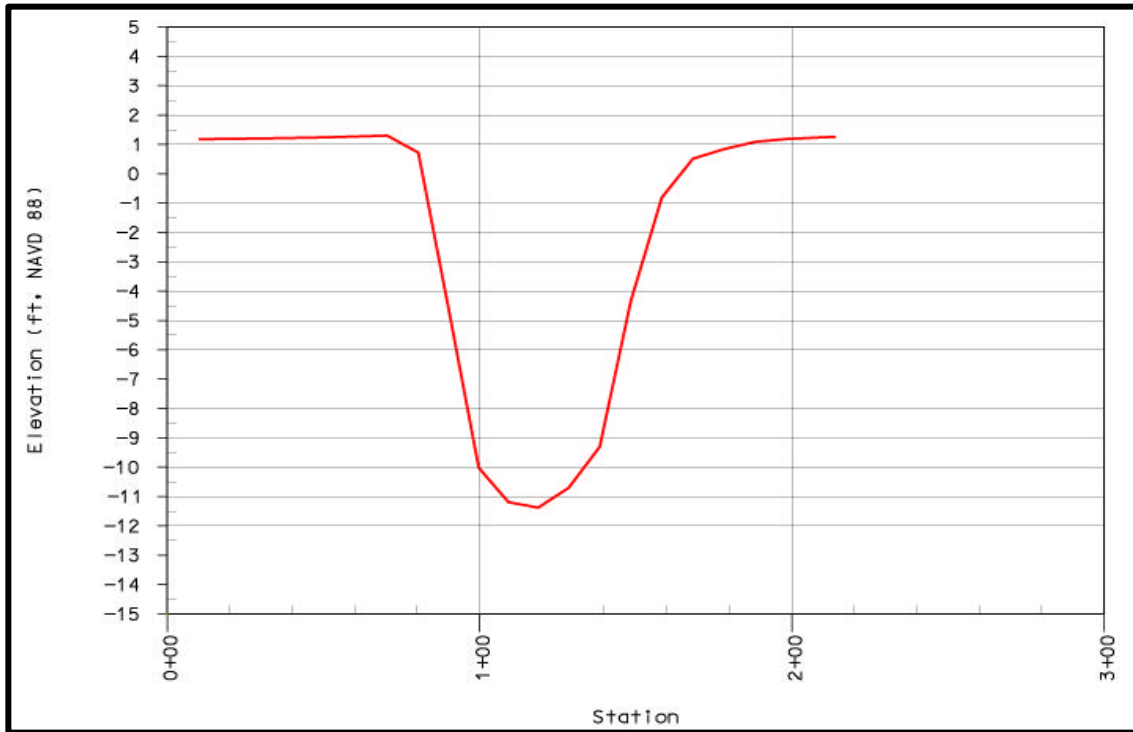


Figure 2.19: Cross Section K

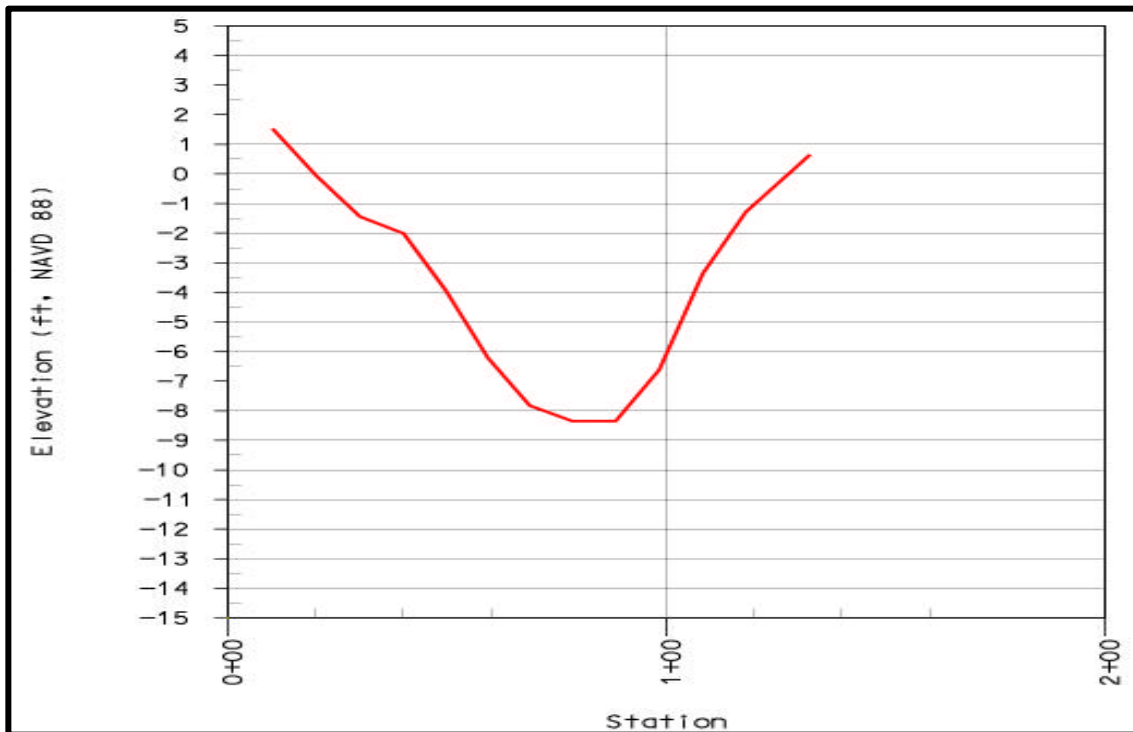


Figure 2.20: Cross Section L

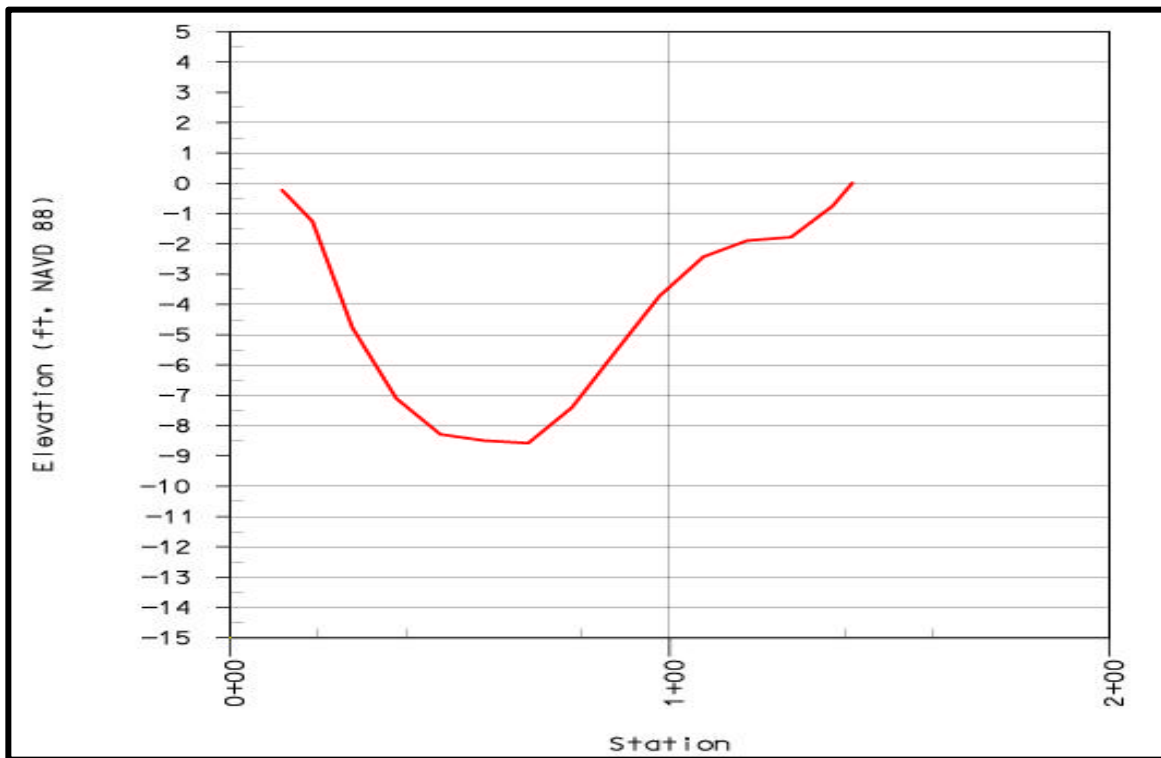


Figure 2.21: Cross Section M

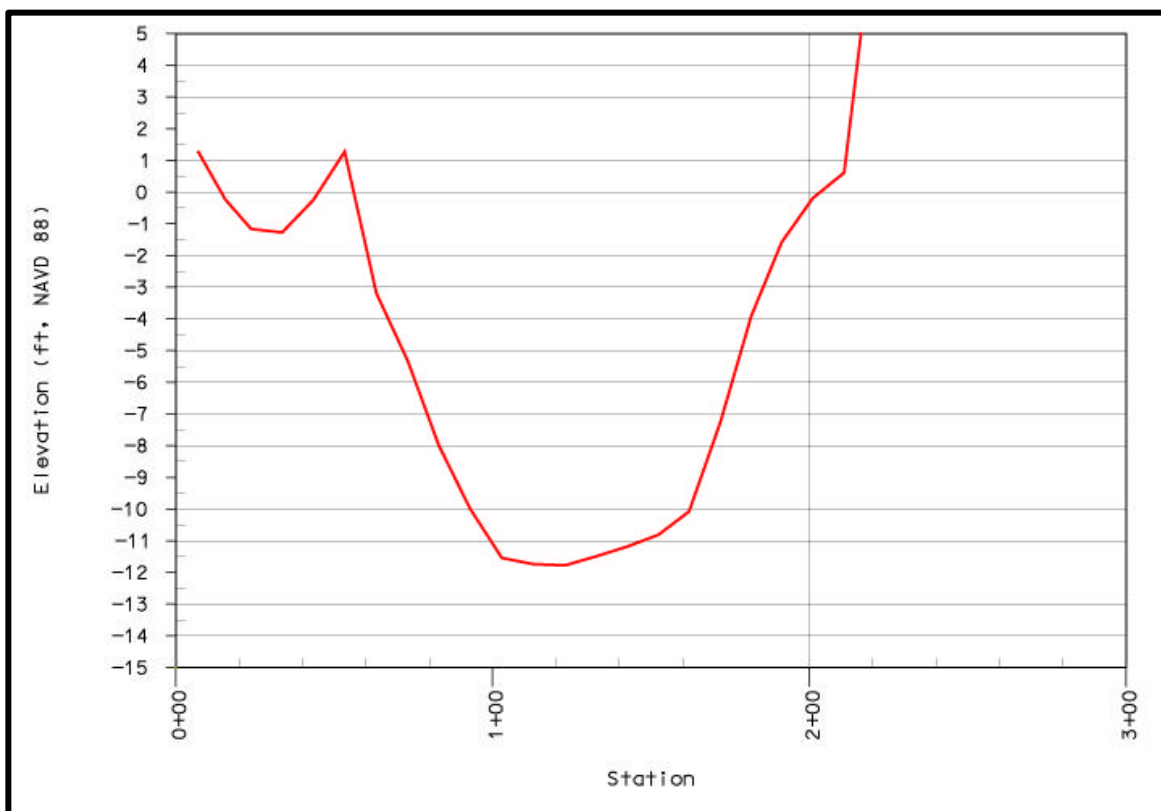


Figure 2.22: Cross Section N

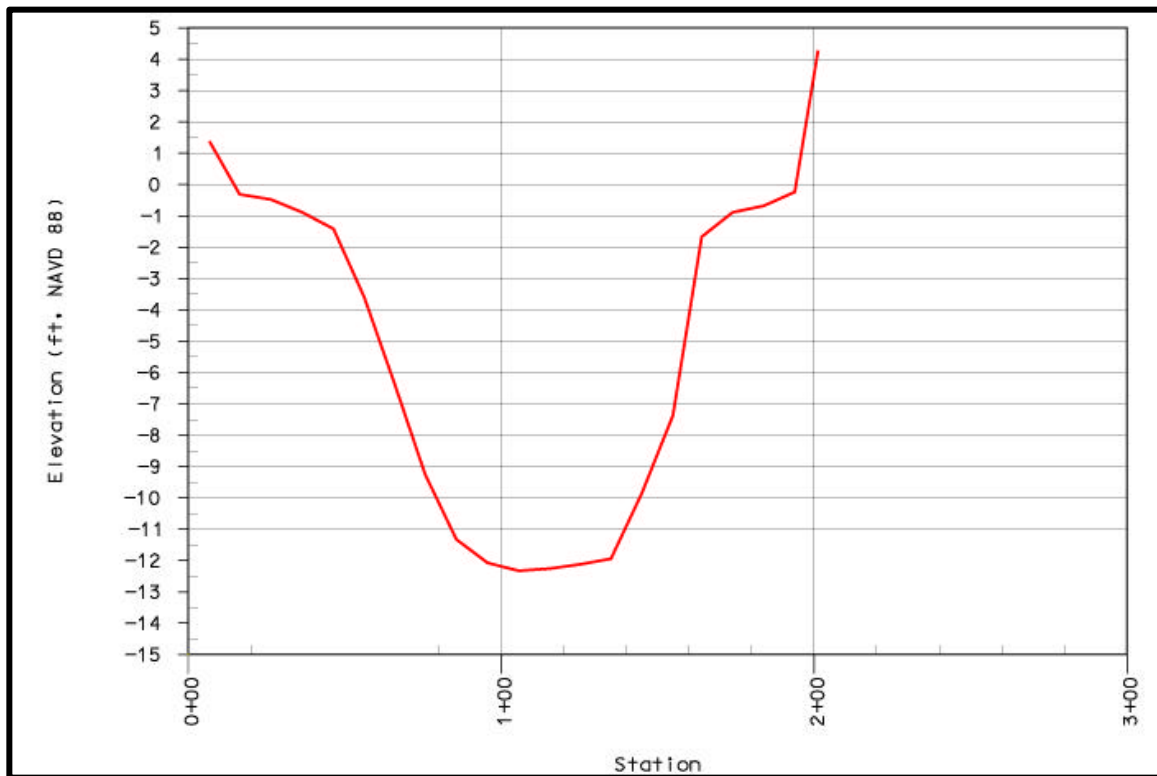


Figure 2.23: Cross Section O

## 2.2.2 HYDROLOGIC DATA COLLECTION

Existing hydrologic data was collected at specific locations within the project limits. The data was collected from continuous recorders owned and operated by either LDNR, USGS, or Louisiana State University- Southern Regional Climate Center (LOSC). Two additional recorders were used as reference gauges from the Davis Pond Freshwater Diversion Project (T-11 and T-18). The information from all the gauges collectively was used to understand the dynamics of the system. As will be later discussed in sections 3.3.1, and 4.2.1, careful analysis of the field data provided information about the system response to, for example, fresh water input from the siphon, and to salinity events from the Barataria Bay. Careful examination of the field data also identified abnormalities in the data recorded at certain stations.

The continuous recorders BA04-07, BA04-10, BA04-17, and BA04-56 were used to calibrate and validate the numerical model, while the discharge of the West Point a la Hache Siphon, and USGS gauge no. 07380251 were used as boundary conditions. Locations of all these stations are shown in Figure 2.24. Table 2.1 provides a summary of the data available for each of the continuous recorders used in this study for the simulation period. A detailed assessment of the quality of the field data is provided in a later section.



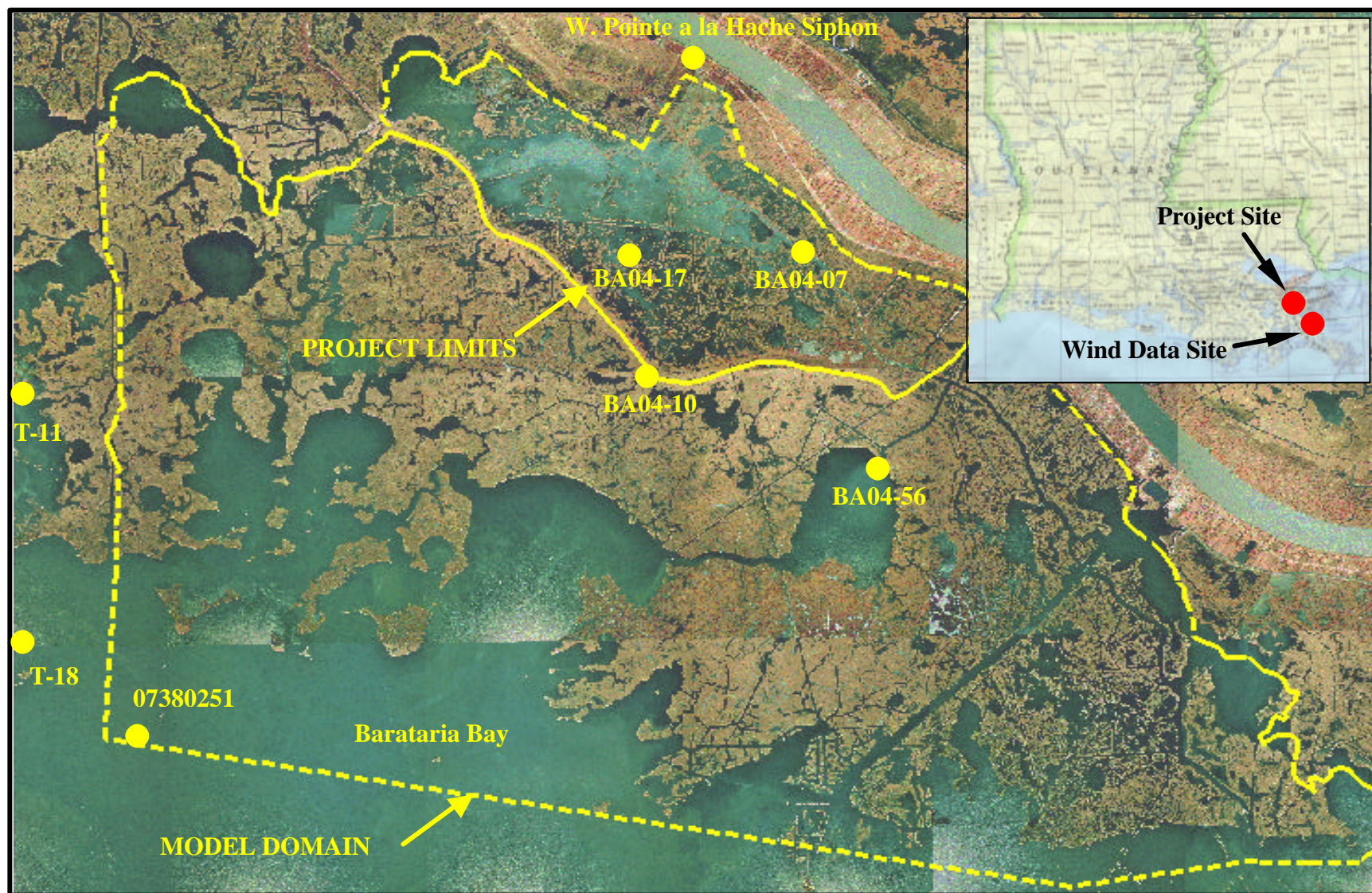


Figure 2.24 Location of Continuous Record

**Table 2.1:** Data Availability for Model Simulation Period

			1998												1999												2000												2001												2002											
	Type	Owner/Operator	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12												
<b>Water Level Gauges</b>																																																														
BA04-7	C	LDNR																																																												
BA04-10	C	LDNR																																																												
BA04-17	C	LDNR																																																												
BA04-56	C	LDNR																																																												
07380251 , Barataria Bay N of Grand Isle, LA	B	USGS																																																												
<b>Salinity and Temperature Gauges</b>																																																														
BA04-7	C	LDNR																																																												
BA04-10	C	LDNR																																																												
BA04-17	C	LDNR																																																												
BA04-56	C	LDNR																																																												
07380251 , Barataria Bay North of Grand Isle, LA	B	USGS																																																												
<b>Discharge Gauge</b>																																																														
West Point a la Hache Siphon	B	LDNR																																																												
<b>Wind Station</b>																																																														
Boothville, Louisiana (Meteorological Station)	W	LOSC																																																												

B = Boundary Gauge

C = Calibration Gauge

W = Wind Speed & Direction Gauge

□ Indicates missing or partial record during that month



### III. CHAPTER THREE

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#### 3.1 MODEL SETUP

Setting up a numerical model for a given project includes the following steps:

1. Determining the extent of the numerical model domain. Care should be taken to ensure that:
  - ?? The boundaries of the model extend beyond the area of interest.
  - ?? The hydrologic or topographic adjustments and changes within the project area do not impact the conditions at the numerical model boundaries.
2. Determining the proper resolution for the computational grid such that it captures the topography of the project area and captures the important channels carrying and transporting water to and from open water bodies.
3. Assigning surveyed or estimated elevations to every node in the computational grid.
4. Including all hydraulic structures within the numerical model domain.
5. Assigning proper boundary conditions to each open water boundary and each fresh water inflow.

The model domain was extended into Barataria Bay such that USGS Gauge 07380251 can be used as a boundary condition for water level and salinity. The extent of the model domain is shown in Figure 2.8.

The surveyed spot elevations shown in Figure 2.2, the Bayou Grand Chenier bank elevations, and channel cross sections were combined with the digitized bank lines (interface between open water and marsh shown in Figure 3.1) to generate the bathymetry input file for the numerical model. Two computer software packages, namely Microstation and Tecplot were used to generate a 50-meter digital elevation model for the project area based on the field survey information.

As discussed in chapter 2, the grid resolution for this project is 50 meters (approximately 164 ft) in both directions in the horizontal plane. This grid resolution is adequate to capture the main bayous and channels within and in the vicinity of the project area. Selection of this grid resolution was also adequate to capture the circulation patterns of water level and salinity within the model domain.

It should be noted that the vertical datum for the bathymetric data as well as the water level data was set to NAVD88, while the horizontal datum was set to state plane coordinates Louisiana South Zone, NAD83.



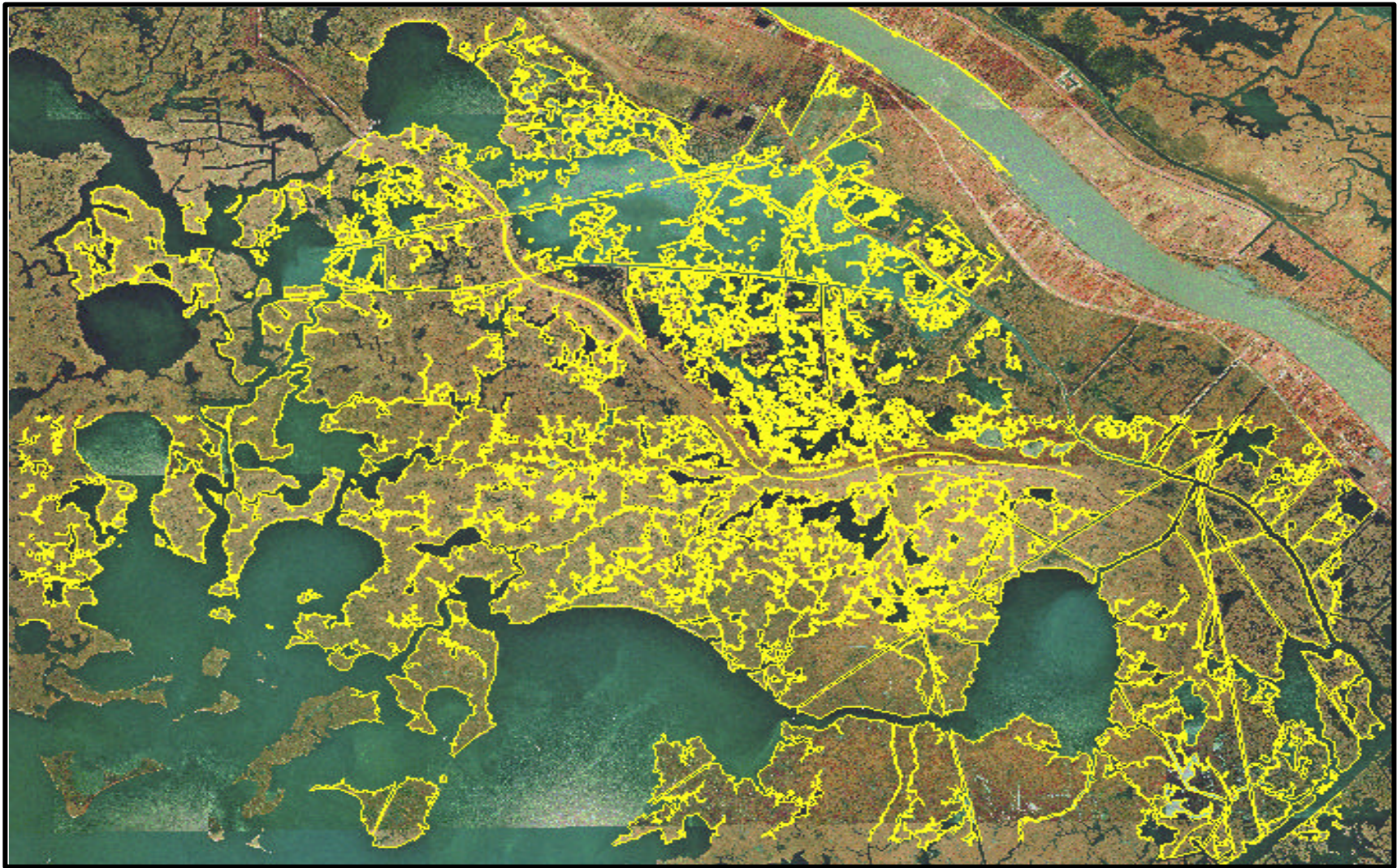


Figure 3.1: Digitized Land Water Interface

### 3.2 MODEL BOUNDARY CONDITIONS

The model domain is shown in Figure 2.8. The water level and salinity measurements at USGS Gauge 07380251 were used as the boundary conditions along the southern boundary of the model domain. The field measurements of the siphon discharge were used as the fresh water inflow into the model domain. A non-reflective boundary condition was used at the western boundary of the model domain. There are no field measurements available at the western boundary; therefore, the best option available was the non-reflective boundary type. A non-reflective boundary is a numerical boundary type typically used when a given edge of a model domain is open water (versus solid edge, e.g. bank line, shoreline, etc.), and at which there are no measurements available.

Including the wind shear stress in the governing equations allows H3D to account for wind friction on the water surface. The model uses the wind data to calculate the shear stresses onto the water surface. Two types of wind data are needed for the model, wind direction and wind speed that in turn dictate the magnitude and the direction of the wind shear stresses on the water surface. For this numerical model, the effects of wind stress were globally applied to the model domain, meaning that the wind varied with time and was constant within the spatial domain of the model. Wind data was collected at the USGS Gauge 07380251.

Rainfall was not accounted for in this modeling effort. The siphon discharge was the only freshwater input used.

The records for the USGS gage used as a boundary condition included some missing data. To allow for the simulation to continue, an assumption of still water level at elevation of 0.0 NAVD88 and an interpolated salinity value (based on the recorded salinity value immediately preceding and following the gage down-time) were used as an assumed boundary condition. However, it is suggested that no conclusions should be drawn based on the performance of the hydraulic structures during these time periods. These assumptions were made merely to allow the simulation to continue. The analysis and observations are made based on time periods where the USGS gauge was functional.

### 3.3 MODEL CALIBRATION

There are numerous peer-reviewed publications that report numerical model studies similar to that presented herein, e.g. (Blumberg<sup>1</sup> et al, 1999, and Jin<sup>2</sup>, 2000). The acceptable uncertainty level varies depending on the project objective. Based on these publications and previous experience, an uncertainty level of ? 10% and ? 20% for water level and salinity is deemed appropriate for the project studied herein.

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<sup>1</sup> Blumberg A. F., Khan L.A., John J.P. (1999). Three-Dimensional Hydrodynamic Model for New York Harbor Region, *Journal of Hydraulic Engineering*, Vol. 125, No. 8.

<sup>2</sup> Jin K.R. (2000). Application of Three-Dimensional Hydrodynamic Model for Lake Okeechobee. *Journal of Hydraulic Engineering*, Vol 126, No.10.

Prior to discussing the model calibration, a detailed analysis and assessment of the quality of the field data should be presented. There were four continuous recording stations, namely BA04-07, BA04-10, BA04-17, and BA04-56, used to calibrate and validate the model, while the USGS Gauge 07380251 was used to provide the Barataria Bay tidal and salinity conditions. The conditions at the USGS gauge will be referred to herein as Boundary Condition (or B.C.). It should be noted that the location of this USGS gauge is at the southwest corner of the modeled area. There were no other continuous recorders available in the Bay to be used as boundary conditions. Therefore, the information at this gauge was assumed applicable across the entire southern edge of the modeled area.

The water depth at BA04-07, BA04-10, BA04-17, and BA04-56 is shallow. Hence, the salinity is well mixed over the vertical water column. Therefore, it is valid to compare the field data within the project area to any layer in the computer model. For convenience, the model output near the water surface was compared to the field measurements. As discussed earlier, the purpose of using a 3-D model for this project is to capture the vertical stratification of salinity in Barataria Bay and adequately reflect that effect to the salinity pattern in the project area.

### **3.3.1 ANALYSIS OF FIELD DATA:**

#### Gauge BA04-56:

This gauge is located outside the project area. It is the most southerly gauge used in the calibration process (closest gauge to the Barataria Bay area). The tide and salinity conditions at this gauge should resemble to some extent the conditions at Barataria Bay (again designated in the figures as B.C.).

Looking at Figure 3.2, which represents the water level conditions at this gauge compared to the boundary conditions, few observations can be made. In Figure 3.2 it can be observed that at low tide the water levels at the gauge dips lower than the Barataria Bay conditions (Figure 3.2, April 2000). On the other hand, during the months of August and September, the water level at the gauge especially at high tide conditions rise by as much as 0.7-0.8 feet higher than the Barataria Bay conditions. In general, the tidal fluctuations should decrease as it progresses inland. The observations at this gauge location do not follow the projected trend. The excessive dipping and rising above the Barataria Bay conditions cannot be explained. It should be noted that these uncertainties in the measurements may cause deviations from the model results.

Figure 3.3 shows the salinity conditions at the gauge compared to Barataria Bay for the whole year of 2000. The trend of the salinity conditions at the gauge compares well with the Barataria Bay conditions.

#### Gauge BA04-07:

This gauge is located along Grand Bayou. Figure 3.4 shows water level data at this gauge compared to the conditions at Barataria Bay. Overall, the tidal observations at this station



seem to be reasonable. Occasionally, the water level at low tide at this gauge dips lower than the Barataria Bay conditions by as much as 0.7 to 0.8 ft.

Figure 3.5 shows the salinity conditions at the gauge compared to Barataria Bay. The overall trend of the salinity at the gauge seems reasonable. The effect of the siphon's fresh water discharge in early March and June is visible. Whenever the siphon is operational, the salinity level at the gauge drops.

During the period of mid April to early June (as highlighted in Figure 3.5), there was a noticeable increase of the salinity at the gauge while the salinity level in the Bay was fairly uniform. In fact, the salinity level at the gauge exceeded that of Barataria Bay. Monitoring personnel examined the data and calibration sheet for Station 07 from the above time period, and although the salinity increased during that period, there was no indication that the data were in error. However, a relatively large shift (correction factor) was applied to the data. Data shifting corrects for biofouling of the data. Such uncertainties in the field measurements interfere with the model calibration and preclude objective evaluation of the model performance for this particular time period.

#### Gauge BA04-10:

As can be seen in Figure 3.6, the water level at this gauge (with the exception of the months of January and February) is significantly lower than Barataria Bay, sometimes by as much as 1.5 ft.

Figure 3.7 shows the salinity conditions at this station compared to the conditions of Barataria Bay. The salinity fluctuations in the first six months of the year 2000 include instances indicated by arrows in Figure 3.7 that need further investigation.

Figure 3.8 shows the salinity conditions at the gauge along with conditions at Barataria Bay and at gauge BA04-07 (on Grand Bayou) for the months of January through March. It should be noted that the siphon was not operating during these months. During the first half of the month of January, the salinity conditions at this gauge was higher than Barataria Bay and Grand Bayou by approximately 10 PPT. Then it sharply dipped from approximately 28 ppt on January 11, 2000 to less than 15 ppt on January 21, 2000. Neither the conditions at Barataria Bay nor at Grand Bayou can offer an explanation for this behavior. In the middle of February the salinity dropped from approximately 20 ppt to 15 ppt. Again, conditions at Barataria Bay and Grand Bayou did not offer an explanation for this drop in salinity at this gauge.

Figure 3.9 is presented to discuss the behavior occurring during two time periods indicated by Zone I and II. It should be stressed that the salinity increase at this gauge during the Zone I time period is in response to the salinity pattern in Grand Bayou, which is probably triggered by salinity conditions at the eastern side of Barataria Bay. The salinity conditions of the western side of Barataria Bay (which is used as the boundary condition for the computer model) does not correlate well to the changes in salinity observed at gauges BA04-07, or BA04-

10 during this particular time period. On the other hand, the sharp increase in salinity at gauge BA04-10 during the time period of Zone II, cannot be explained. It does not correlate with either Grand Bayou or Barataria Bay conditions.

#### Gauge BA04-17

The water level conditions at this gauge compared to Barataria Bay are shown in Figure 3.10. The correlation between the two conditions is quite reasonable. It should be noted that the gauge malfunctioned from middle summer to early winter. Figure 3.11 shows the salinity conditions at this station compared to Barataria Bay. This gauge experiences the same behavior during the Zone I time period as discussed above in regard to gauge BA04-10.

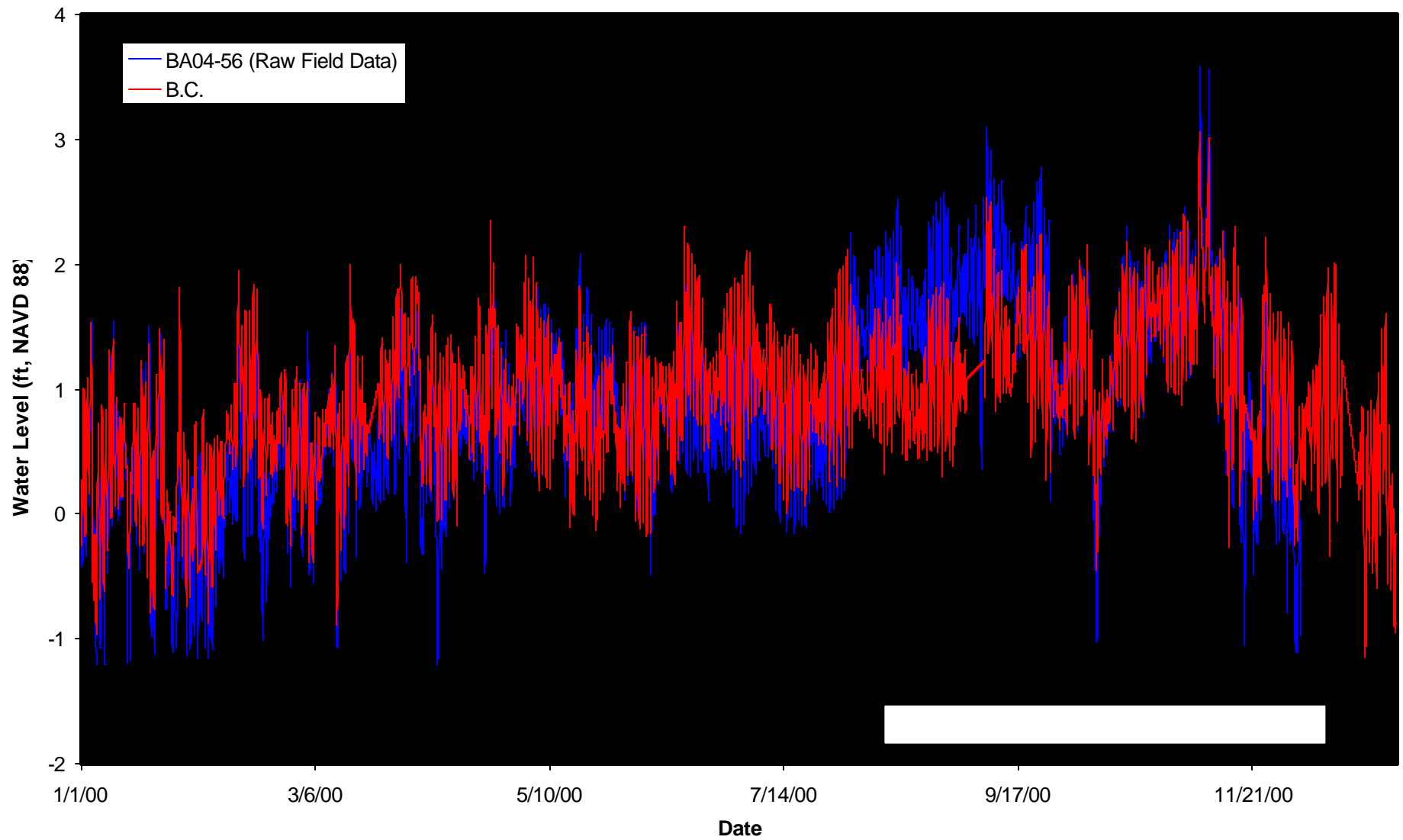


Figure 3.2: Water level at Gauge BA04-56 Compared to B.C. (USGS 07380251: Boundary Condition).



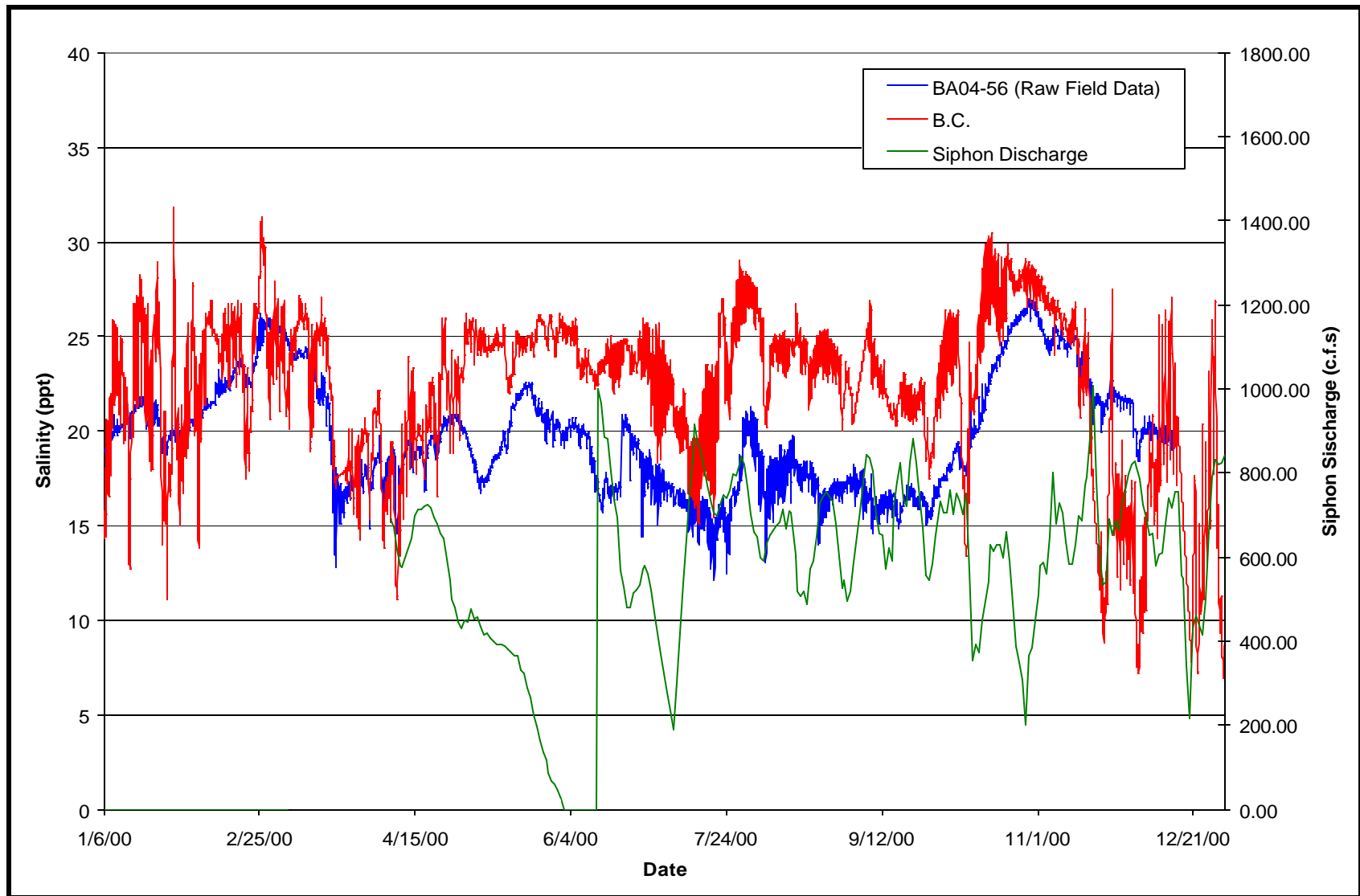


Figure 3.3: Salinity at Gauge BA04-56 Compared B.C. (USGS 07380251: Boundary Condition) with Siphon Discharge Shown.

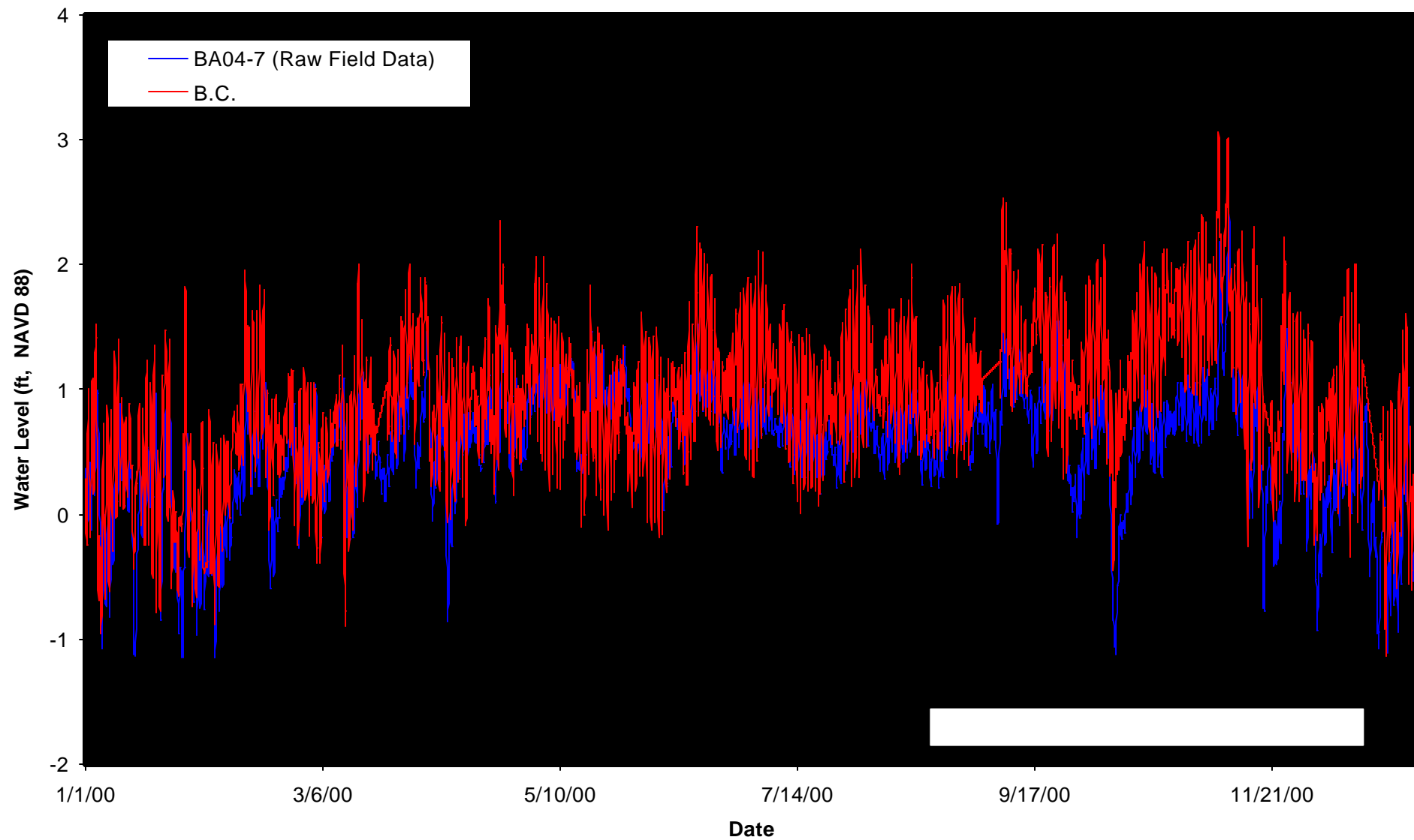


Figure 3.4: Water level at Gauge BA04-07 Compared to B.C. (USGS 07380251: Boundary Condition)

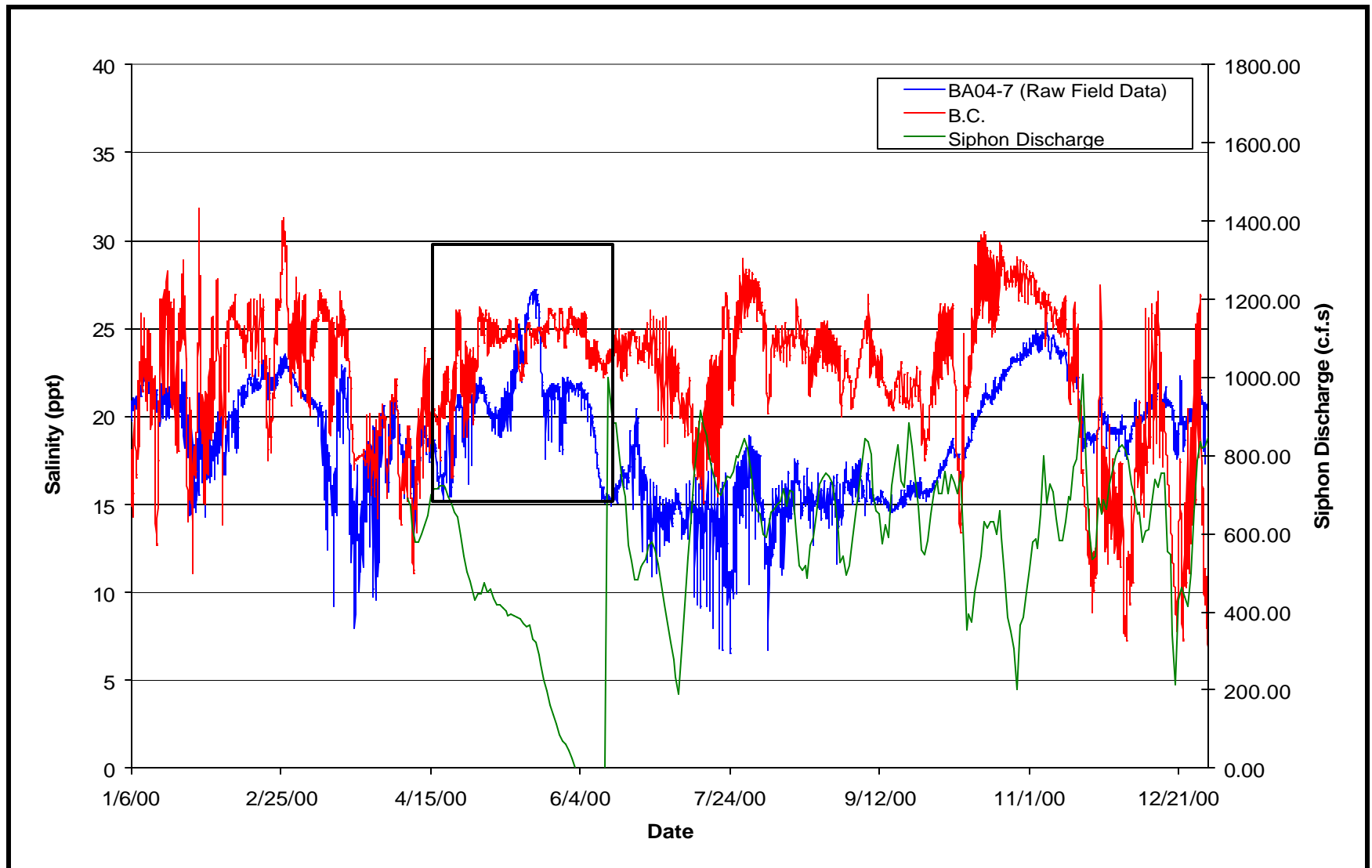


Figure 3.5: Salinity at Gauge BA04-07 Compared B.C. (USGS 07380251: Boundary Condition) with Siphon Discharge Shown



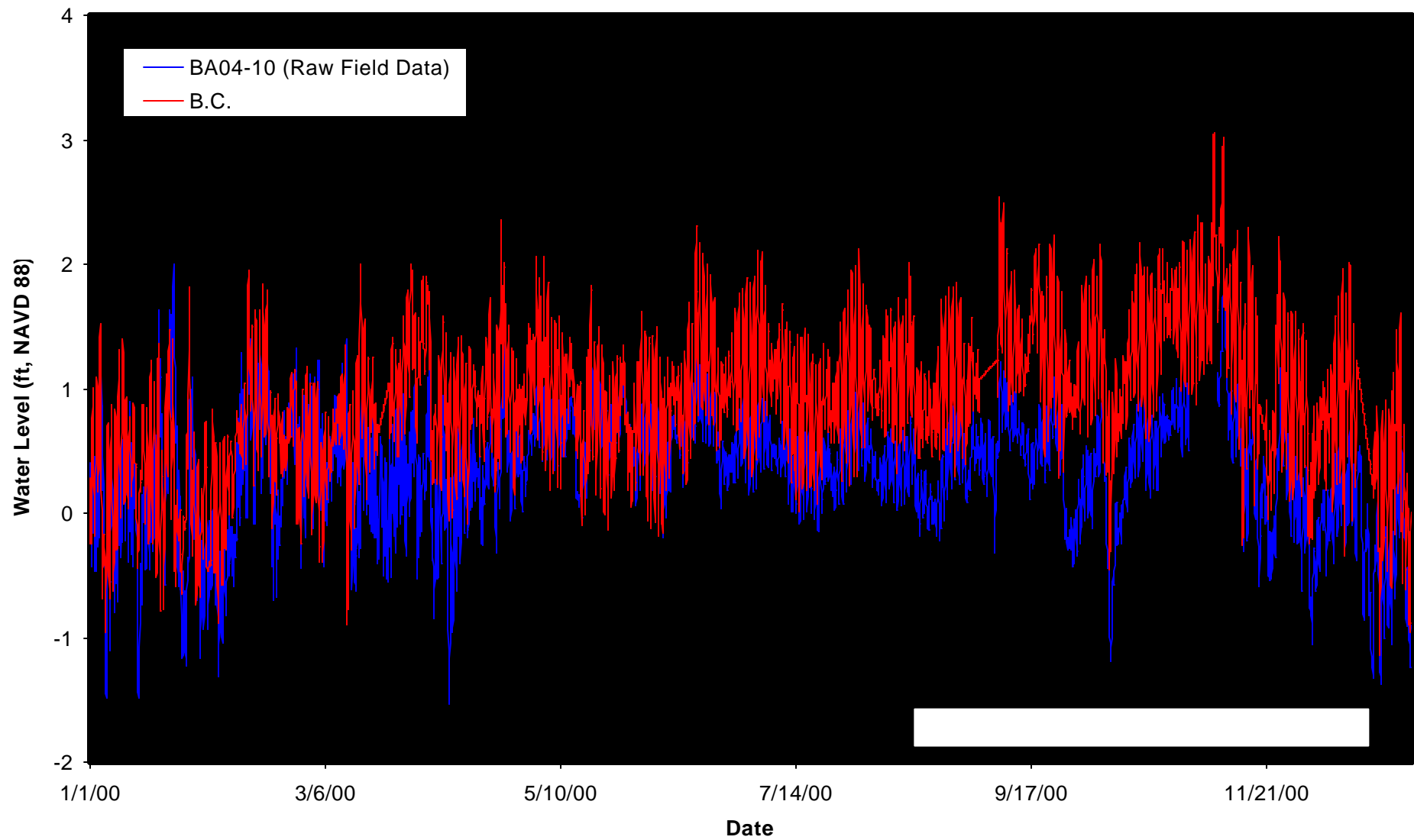


Figure 3.6: Water level at Gauge BA04-10 Compared to B.C. (USGS 07380251: Boundary Condition)

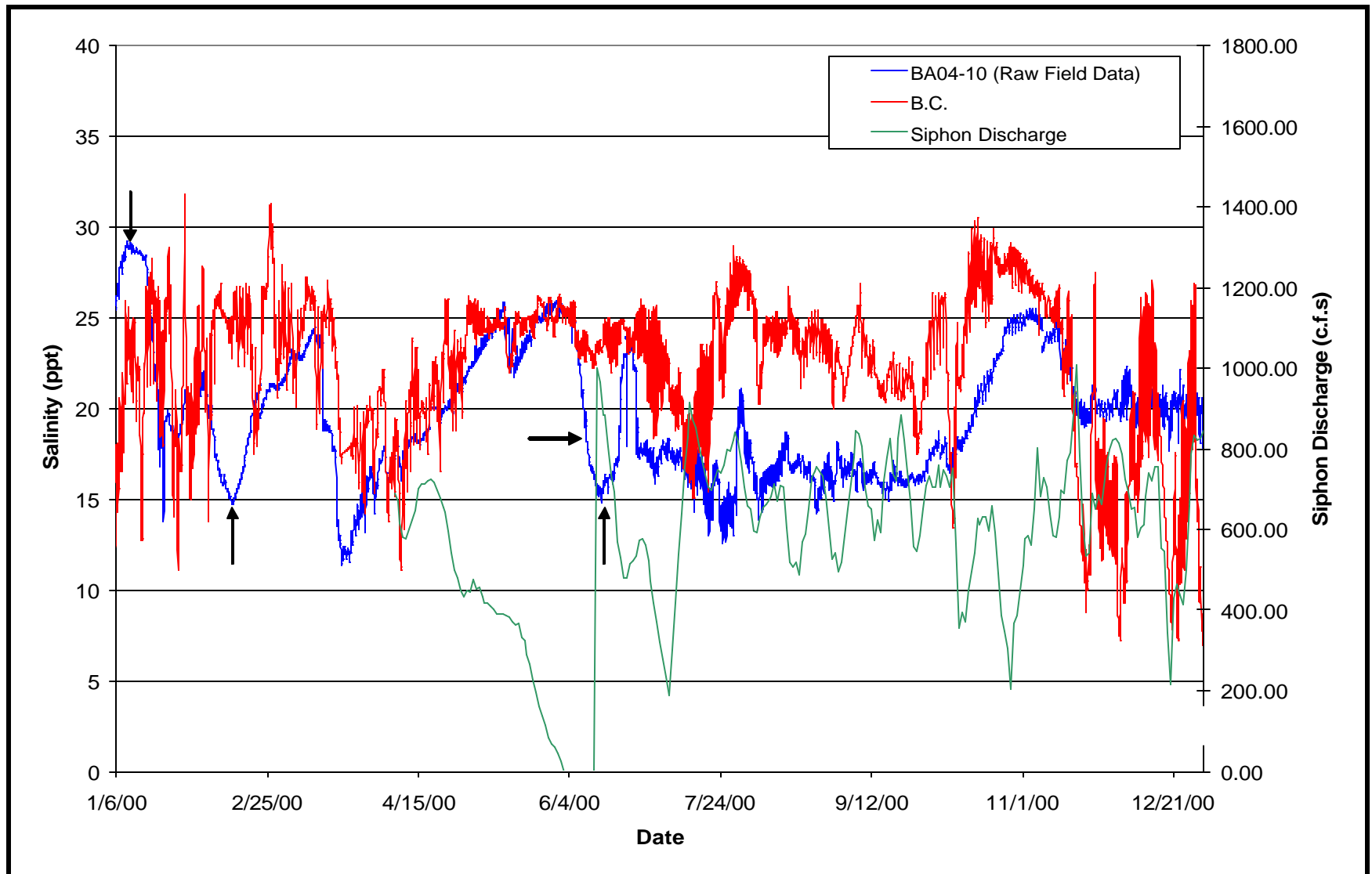


Figure 3.7: Salinity at Gauge BA04-10 Compared B.C. (USGS 07380251: Boundary Condition) with Siphon Discharge Shown

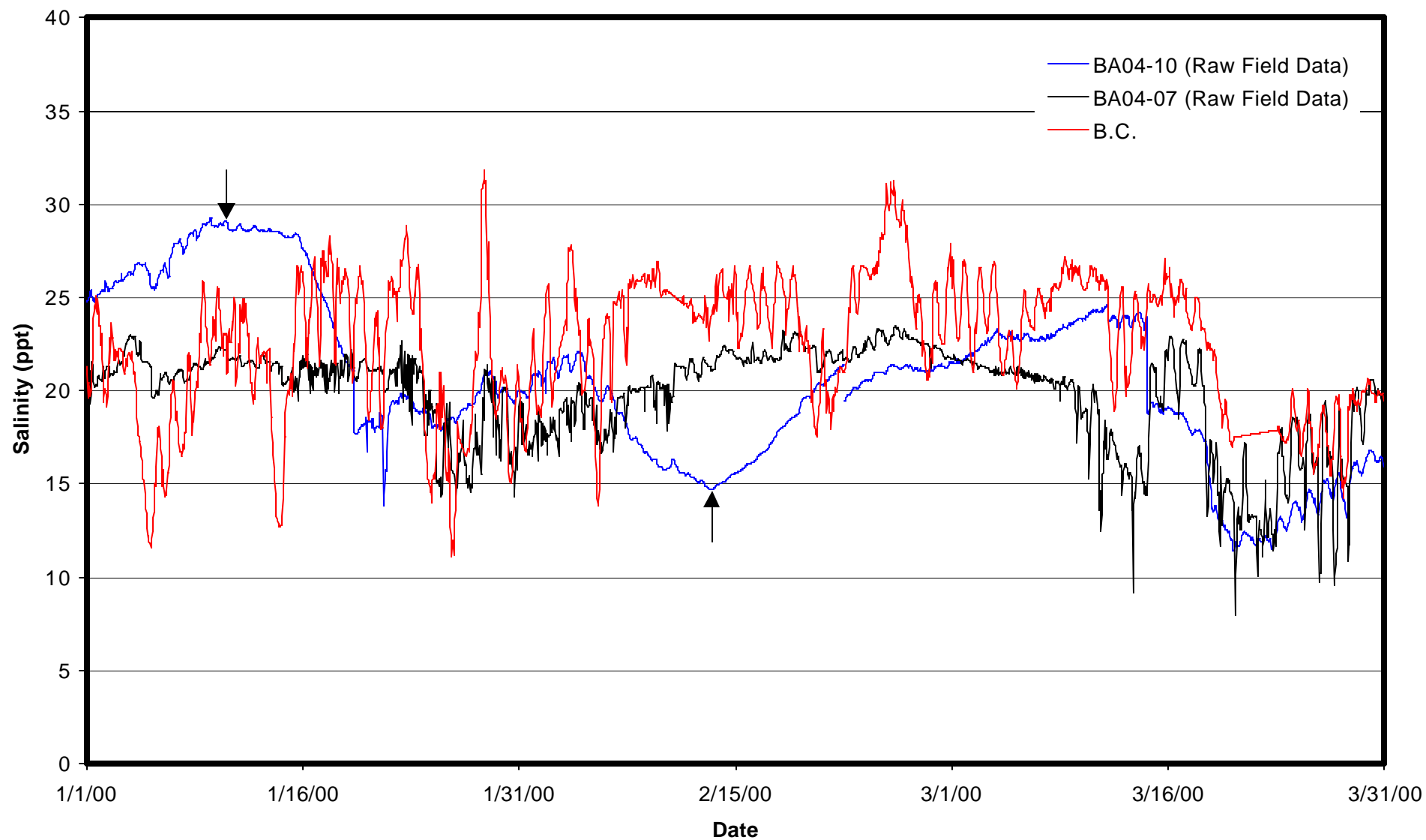


Figure 3.8: Salinity at Gauge BA04-10 Compared B.C. (USGS 07380251:Boundary Condition) With Siphon Discharge for January to March 2000.



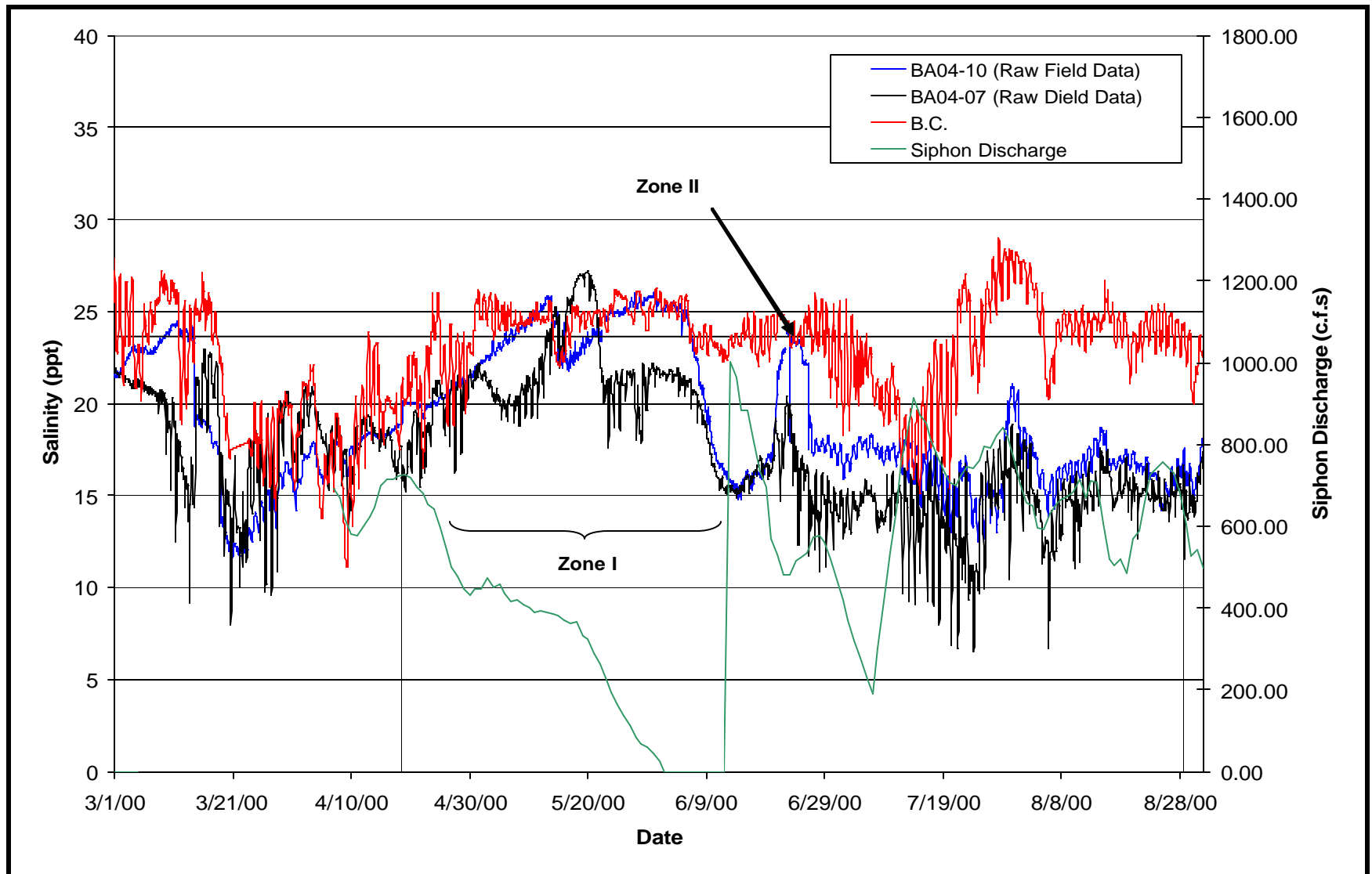


Figure 3.9: Salinity at Gauge BA04-10 Compared B.C. (USGS 07380251: Boundary Condition) with Siphon Discharge for March to August 2000.

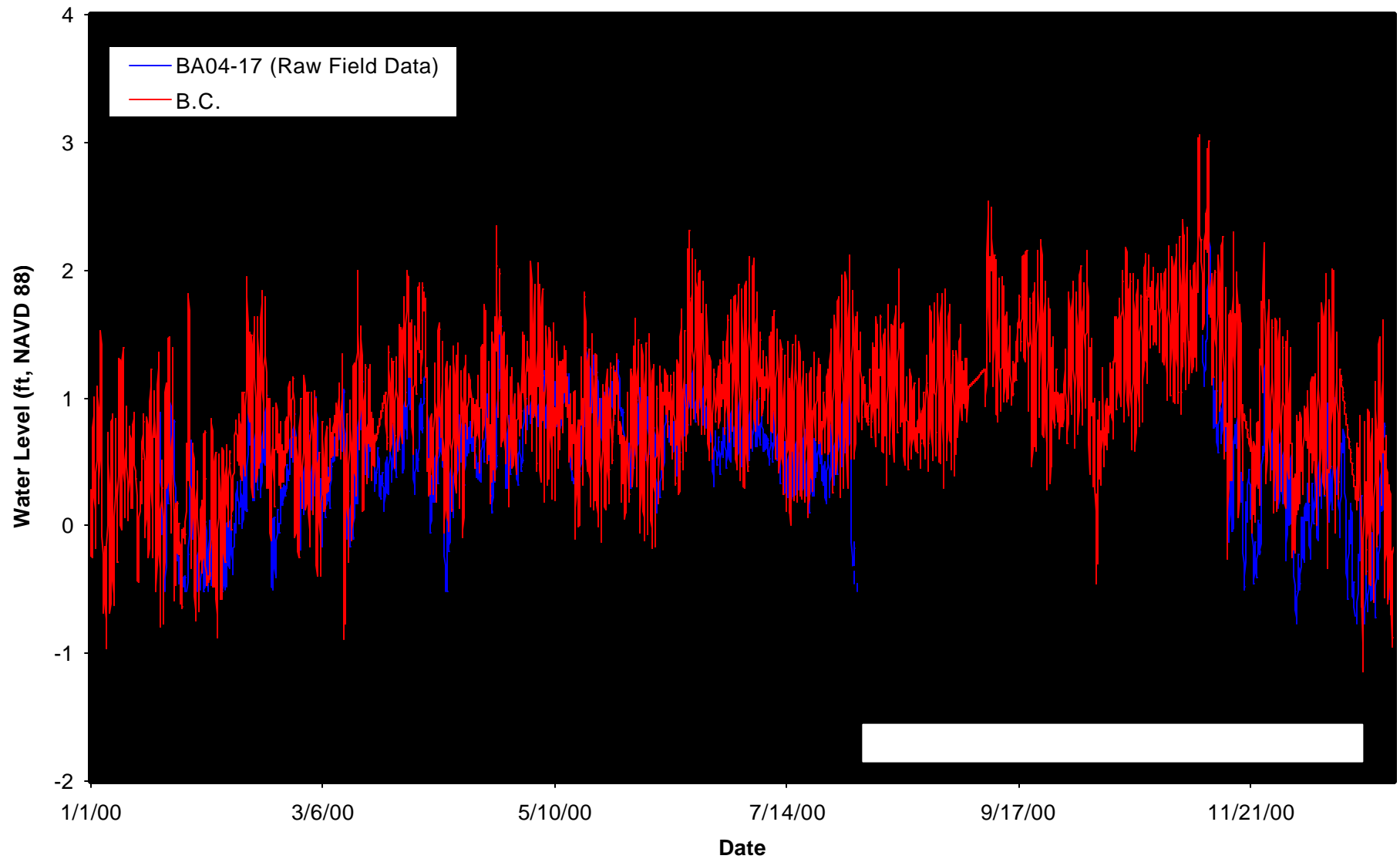


Figure 3.10: Water level at Gauge BA04-17 Compared to B.C. (USGS 07380251: Boundary Condition)

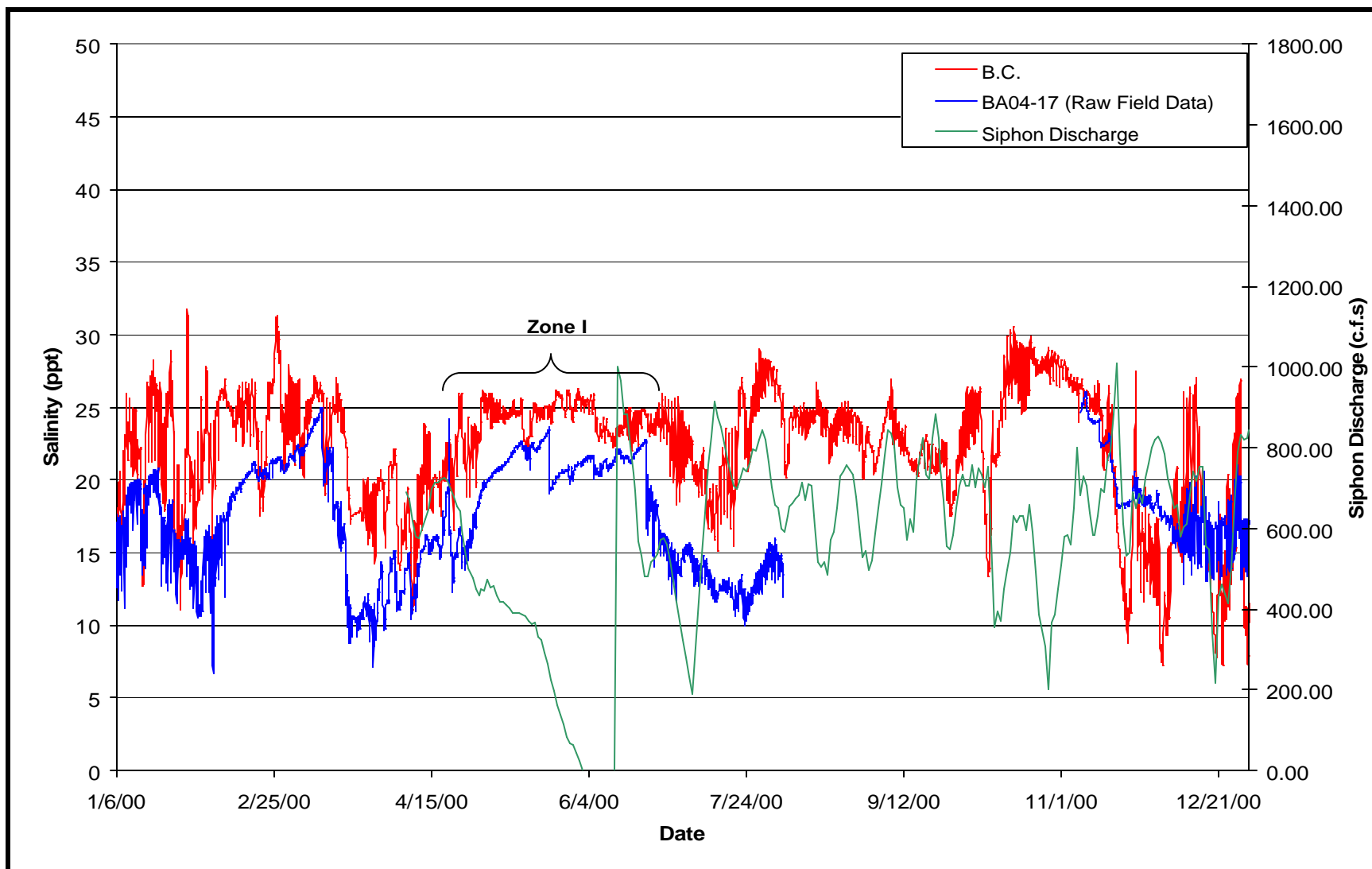


Figure 3.11: Salinity at Gauge BA04-17 Compared B.C. (USGS 07380251: Boundary Condition) with Siphon Discharge Shown



An overall summary table for the field measurements is shown below. It provides information regarding the maximum and minimum measurement at each of the monitoring stations.

**Table 3.1**

Summary of field observations at the four monitoring stations for year 2000

Gauge	Tide		Salinity		
	Maximum	Minimum	Maximum	Average	Minimum
	NAVD 88 (ft)	NAVD 88 (ft)	ppt	ppt	ppt
<b>BA04-07</b>	<b>2.53</b>	<b>-1.15</b>	<b>27.22</b>	<b>18.61</b>	<b>6.54</b>
<b>BA04-10</b>	<b>2.15</b>	<b>-1.53</b>	<b>29.25</b>	<b>19.69</b>	<b>11.38</b>
<b>BA04-17</b>	<b>2.37</b>	<b>-0.77</b>	<b>26.11</b>	<b>17.59</b>	<b>6.67</b>
<b>BA04-56</b>	<b>3.59</b>	<b>-1.21</b>	<b>27.14</b>	<b>19.69</b>	<b>12.15</b>

### 3.3.2. Numerical Model Results:

The list of calibration parameters is provided below:

Parameter Name	Calibrated Value	Parameter Definition
r	0.003	Bottom friction coefficient
ahcon:	1.0	Horizontal eddy viscosity coefficient ( dimensionless)
ah_zero	5.0	Eddy viscosity floor (m2 / s)
stretch	1.0	Stretch, for open boundary condition scalars
diffuse	5.0	Diffuse, horizontal diffusivity m2 / s, for scalars only
ratio	0.4	Ratio of vertical Diffusivity / viscosity (dimensionless)
fianf	30.0	Latitude for coriolis coefficient
htmit	0.75	Weighting for horizontal implicit solution
eps	1.e-7	Sorting coefficient: convergence criteria on elevation (m)
omi	1.6	Minimum omega for sorting
oma	1.9	Maximum omega for sorting
tomi	150.0	Depth at which omega increases
High-water	3.0	Maximum allowed water level for flood/dry
Low-water	-3.0	Minimum allowed water level when considering flood/dry inclusion
Flood-check	0.045	Depth threshold for flooding a cell
dry_check	0.02	Depth threshold for drying a cell must be less than half "flood-check"
za_0	0.0	Initial at-rest water level
z_msl	0.0	Mean sea level with respect to bathymetric data

\* For more detailed information about these parameters please refer to Stronach et. al, 1993)<sup>3</sup>

A quantitative assessment of the model results is provided in Table 3.2. The Root Mean Square Error (RMS) shown in the table is computed according to the following formula:

$$RMS \text{ Error} = \sqrt{\frac{\sum_{i=1}^n |\text{computed} - \text{observed}|^2}{n}}$$

Where the maximum and minimum observed water level and salinity conditions at the four monitoring gauges are shown in Table 3.1.

<sup>3</sup> Stronach, J.A., Backhaus, J.O., & Murty, T.S. (1993). An update on the numerical simulation of the waters between Vancouver Island and the mainland: the GF8 model. *Oceanography and Marine Biology Annual Review*. **31**, 1-86.

#### Gauge BA04-56

The computed water level and salinity conditions at this gauge are shown in Figures 3.12 and 3.13. Model results for water level and salinity conditions compares well with the observed conditions. Additionally, the model follows the trends for both the water level and salinity changes as observed in the field well.

#### Gauge BA04-07

Again, the computed water level and salinity conditions at this gauge compared reasonably well with the observed conditions as shown in Figures 3.14 and 3.15. It is important to note that the siphon discharge was missing from March 6, 2000, to April 6, 2000. There was no information available to estimate the siphon discharge. Therefore, the assumption was made that the siphon discharge was zero during the missing period. It is important to emphasize that the siphon discharge is a driving force, and missing data directly impacts the model performance. The salinity level within the project area is sensitive to the siphon discharge. The salinity level decreases within the project area whenever the siphon is operational.

The computed salinity deviates from the observed conditions during the period of mid April through mid June (time period highlighted in Figure 3.5). The increase in observed salinity was taking place while the siphon discharge was approximately 500 cfs. On the other hand, the salinity predicted by the model, and as expected, dropped in response to the fresh water inflow from the siphon.

As discussed earlier, the salinity observed patterns during this time period cannot be explained by the siphon inflow or by the observed salinities at the USGS gauge no. 07380251, which is located in the southwest corner of the model domain. Additionally, the monitoring personnel of LDNR could not fully verify or explain the abnormal trends observed in the field. It is possible that the salinity measurements at BA04-07 during this time period are erroneous. It is also possible that these abnormal patterns are caused by conditions occurring at the southeast corner of the model domain. However, the USGS gauge is the only continuous recorder available and therefore, the USGS gauge was used as the south boundary condition for the numerical model. It should be noted that the model could not be calibrated to duplicate these abnormalities because of a lack of data. The numerical results on other time periods follow the same trend as the field observations.

#### Gauge BA04-10

The computed water level and salinity conditions at this gauge are shown in Figures 3.16 and 3.17. The agreement between the computed water level changes and the observed water level changes are good as far as trend patterns are concerned, however, the observed water level is lower than the computed water level. The computed salinity compares reasonably well with the observed salinity for the last six months of the year; however, during the first six months of the year of 2000, there were deviations between the computed and the observed salinities. The field observations at this particular gauge show trends that cannot be explained through salinity and water level conditions at Barataria Bay and Grand Bayou. These issues were thoroughly

discussed in the data analysis section earlier. Deviations between the numerical model and the field observations are due to uncertainties in the salinity measurements and the siphon discharge, and possibly the lack of adequate data in the southern portions of the model domain.

#### Gauge BA04-17

The computed water level and salinity conditions at this gauge are shown in Figures 3.18 and 3.19. The model results deviated from the field observation most notably during the first six months of the year of 2000. The observed salinity dropped significantly during the month of March. The drop in salinity indicates that it is possible that the siphon was discharging freshwater into the project area. However, and as indicated before, the siphon discharge was unknown and assumed to be zero. That assumption caused significant deviation between the observed and predicted salinities. Most of the observed salinity record was missing for the last six months of the year of 2000.

Table 3.2 Error Analyses for the Numerical Results

Gauge	Water Level Analysis		Salinity Analysis
	Corr. Coef.	RMS Error %	RMS Error %
<b>BA04-07</b>	<b>0.88</b>	<b>12</b>	<b>18</b>
<b>BA04-10</b>	<b>0.74</b>	<b>18</b>	<b>23</b>
<b>BA04-17</b>	<b>0.81</b>	<b>13</b>	<b>21</b>
<b>BA04-56</b>	<b>0.85</b>	<b>7</b>	<b>19</b>



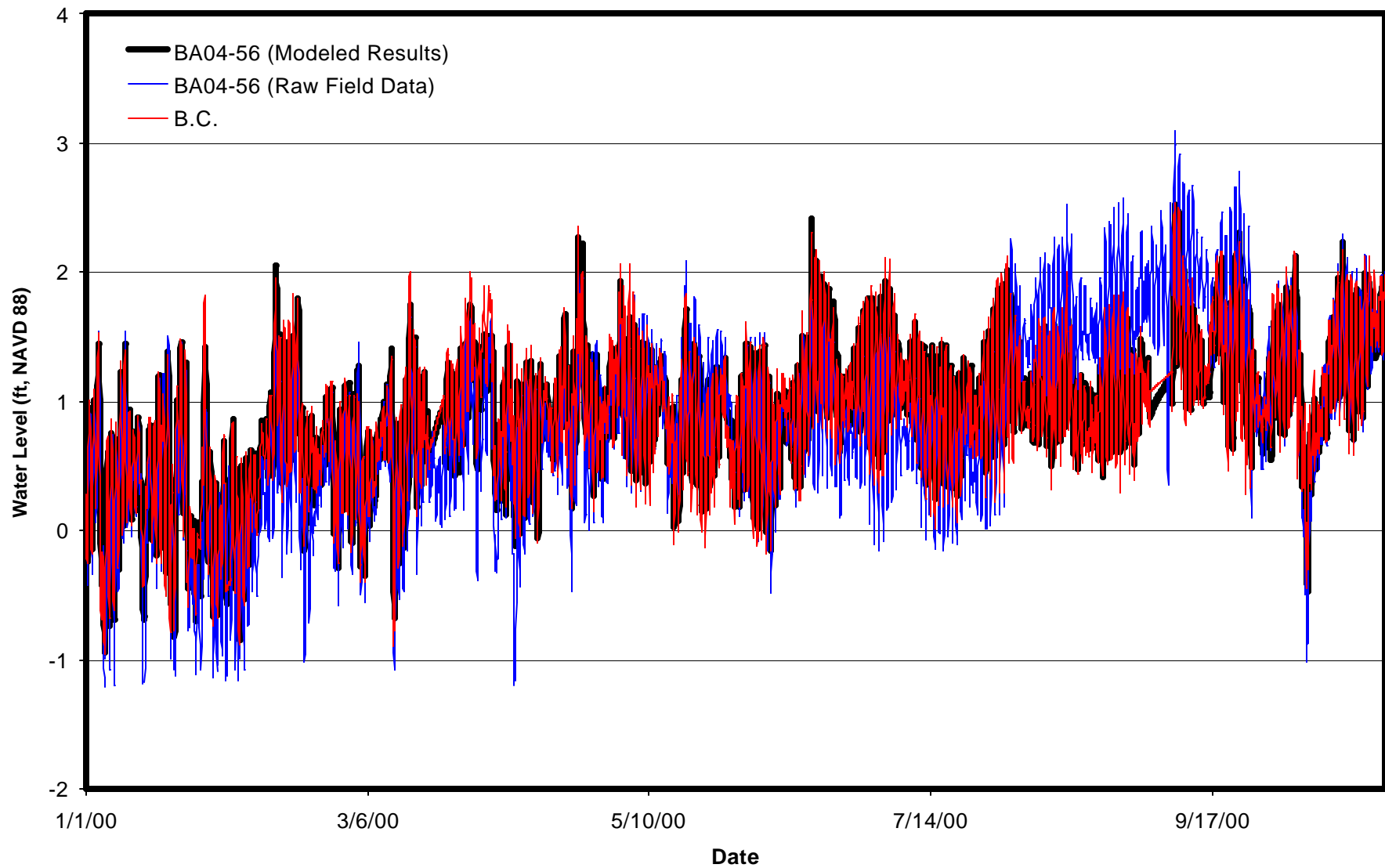


Figure 3.12: Comparison of Water Level Model Results Versus Raw Field Data at Gauge BA04-56 (B.C. - USGS 07380251 Shown for Reference).

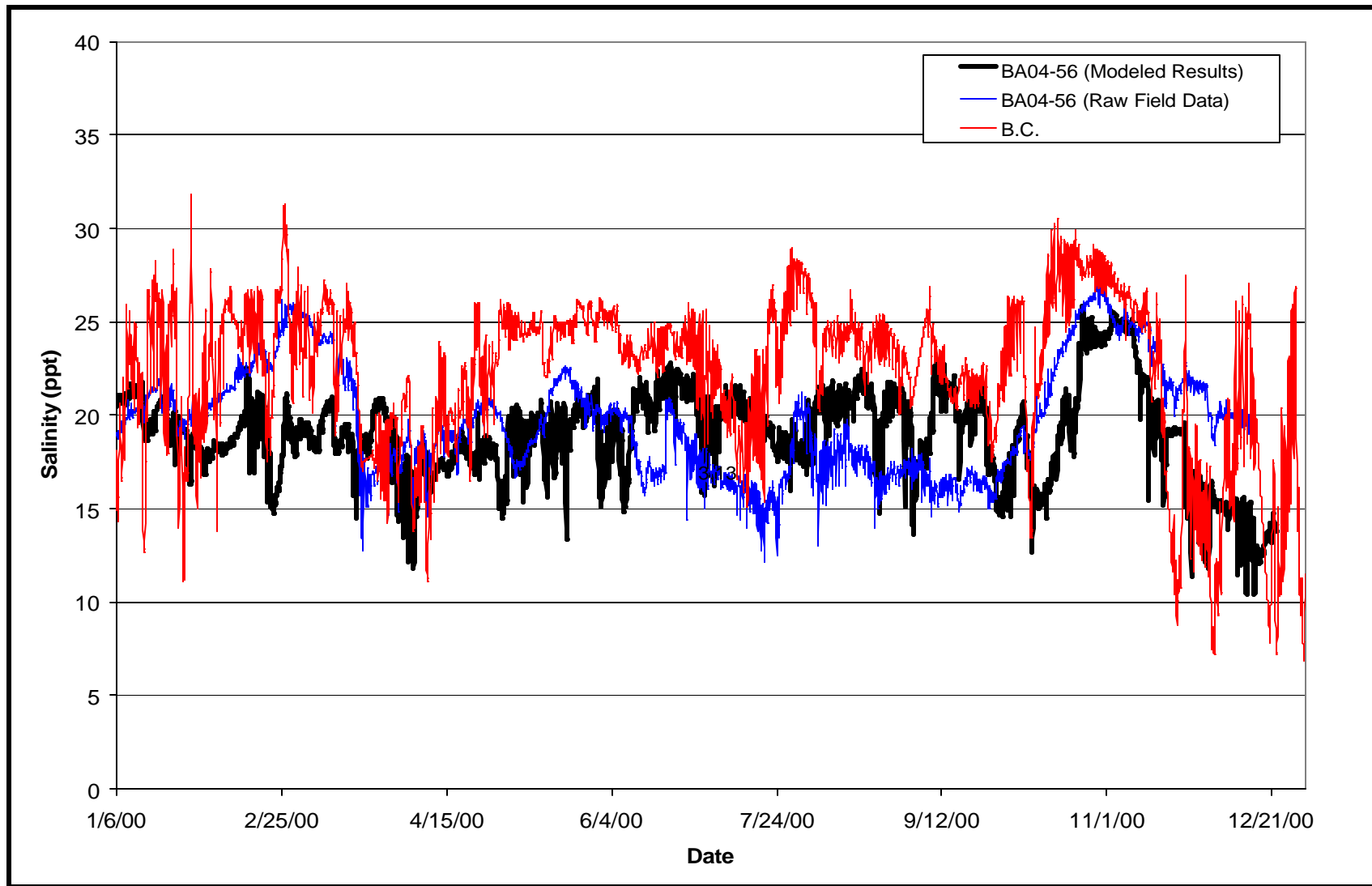


Figure 3.13: Comparison of Salinity Model Results Versus Raw Field Data at Gauge BA04-56 (B.C.- USGS 07380251 Shown for Reference).

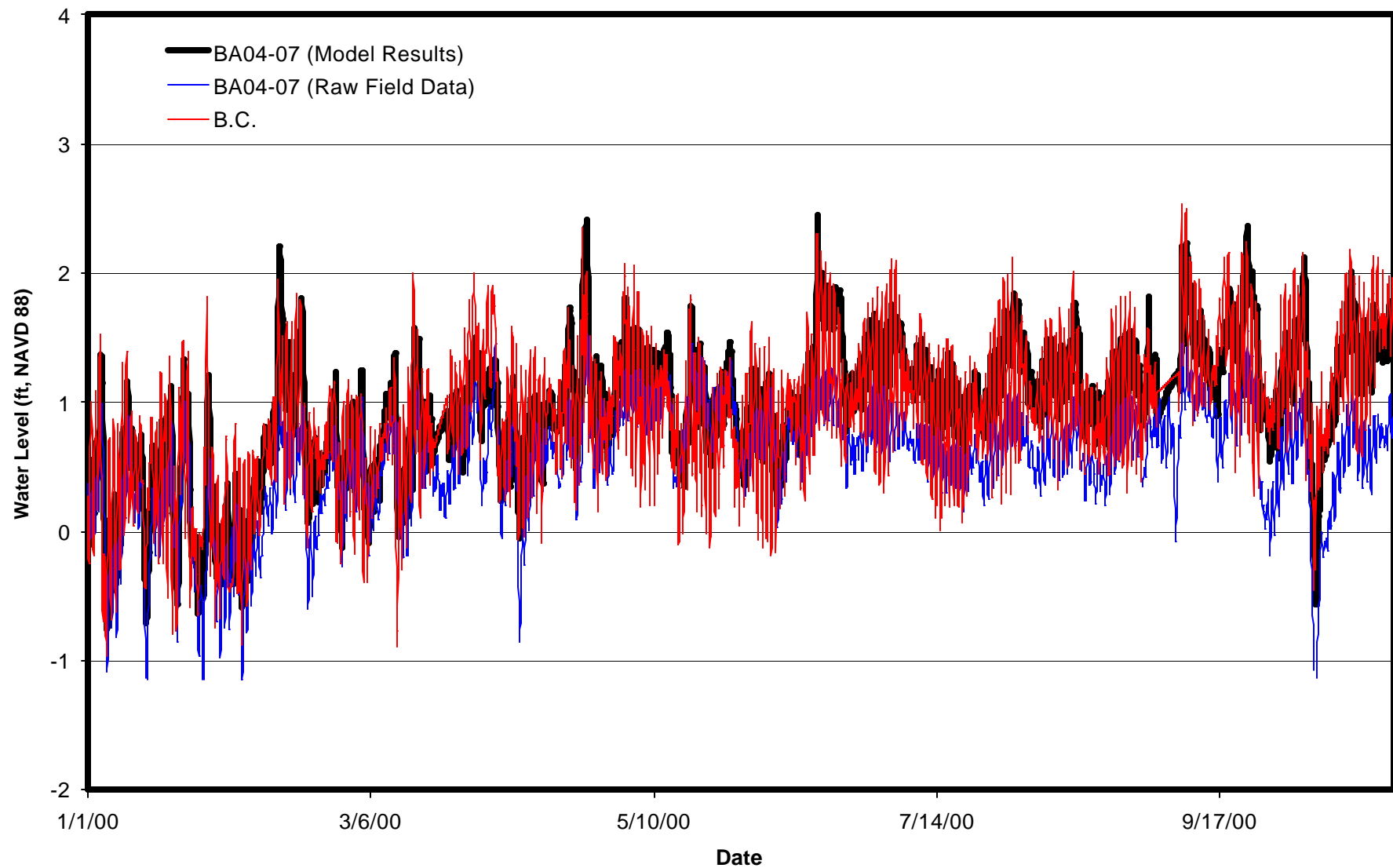


Figure 3.14: Comparison of Water Level Model Results Versus Raw Field Data at Gauge BA04-07 (B.C. - USGS 07380251 Shown for Reference).

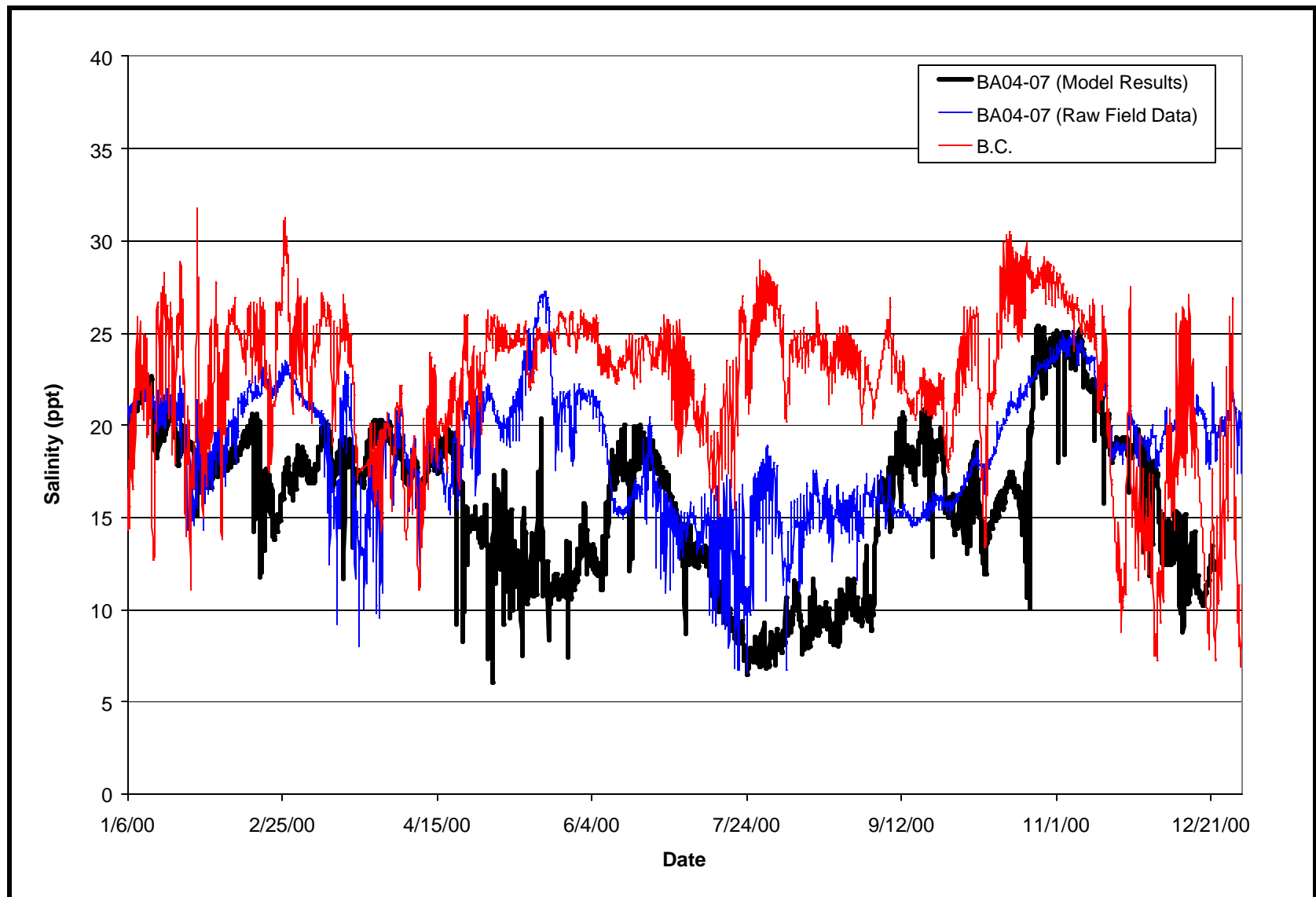


Figure 3.15: Comparison of Salinity Model Results Versus Raw Field Data at Gauge BA04-07 (B.C.- USGS 07380251 Shown for Reference).



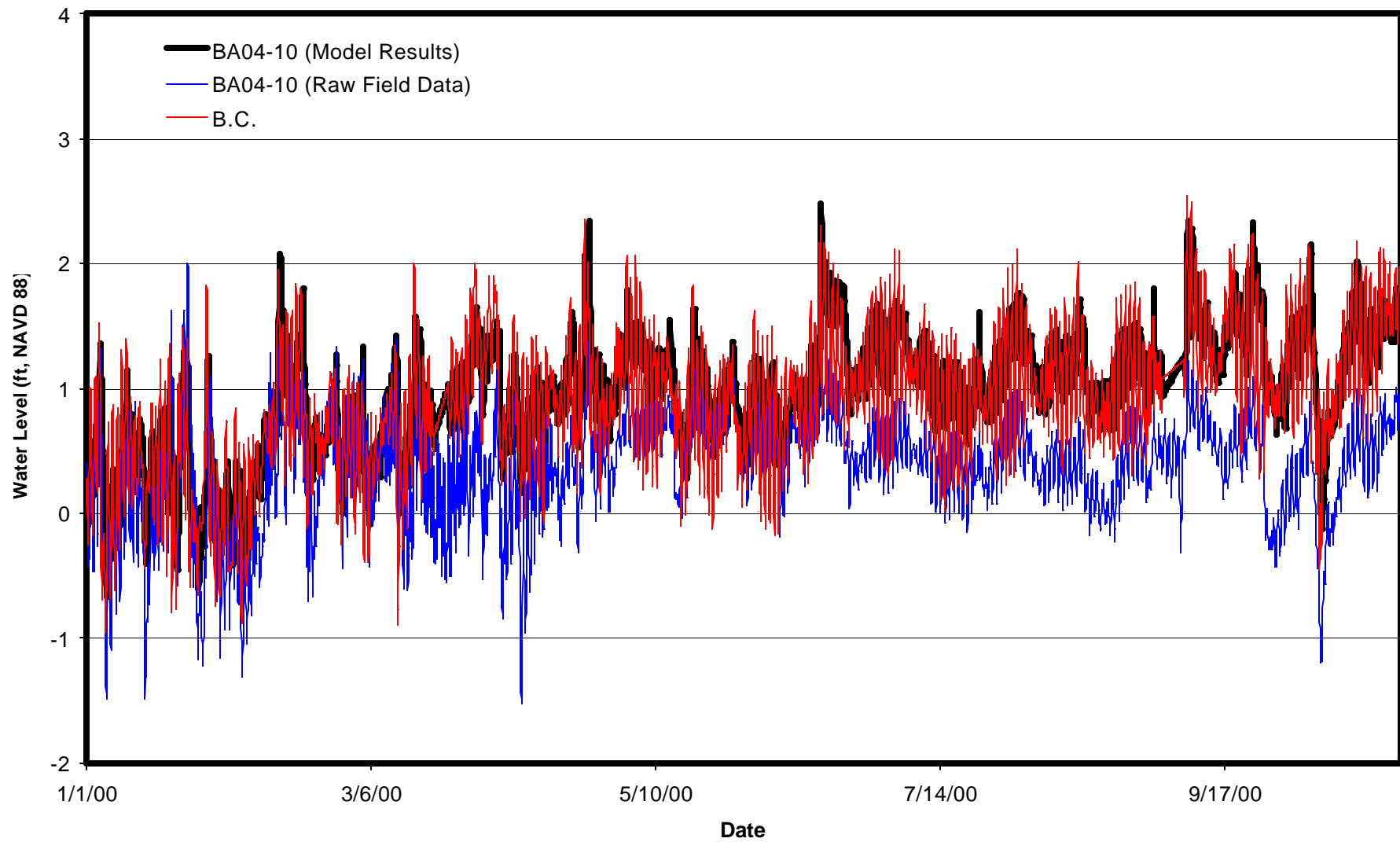


Figure 3.16: Comparison of Water Level Model Results Versus Raw Field Data at Gauge BA04-10 (B.C. - USGS 07380251 Shown for Reference).

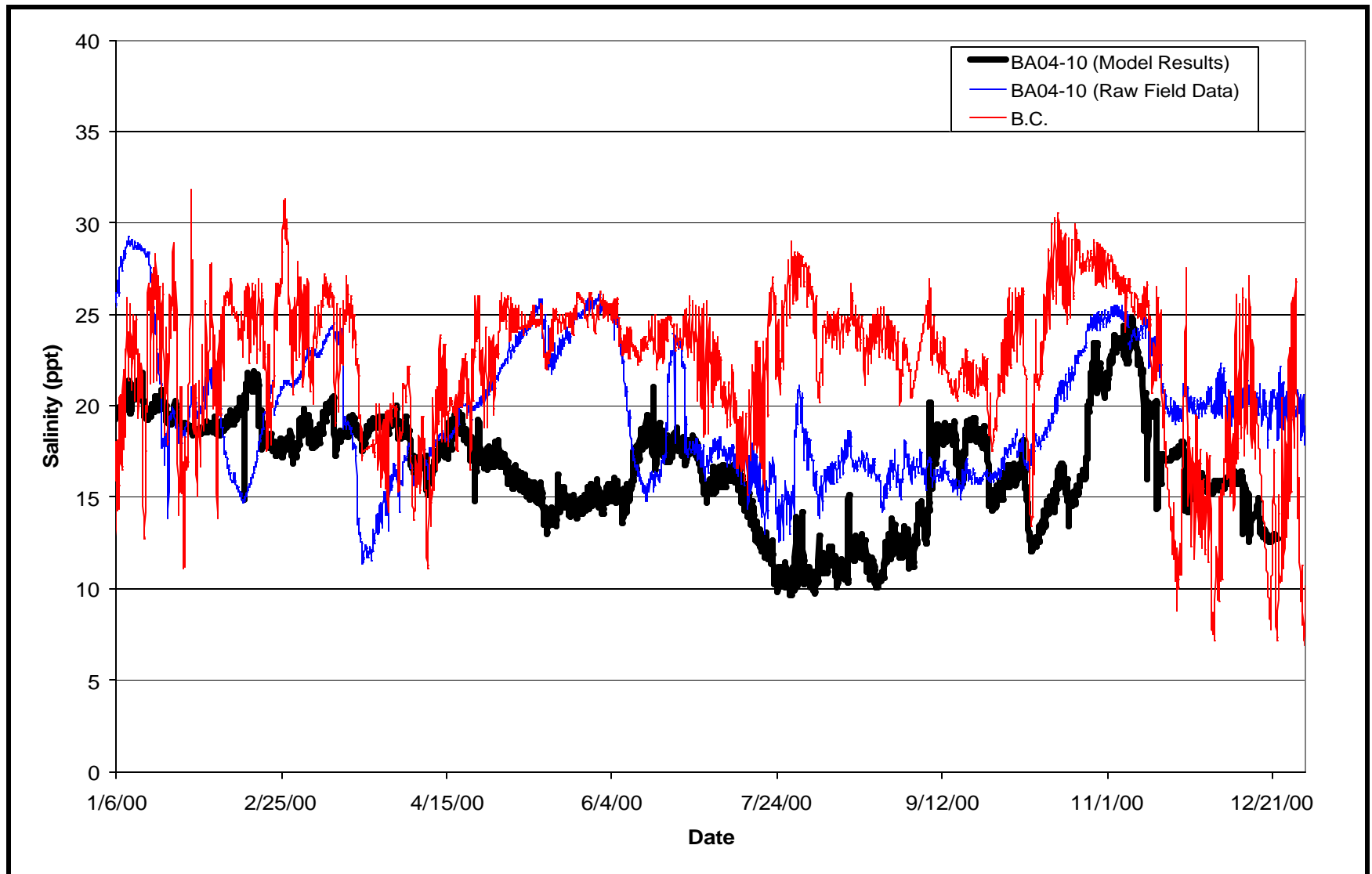


Figure 3.17: Comparison of Salinity Model Results Versus Raw Field Data at Gauge BA04-10 (B.C.- USGS 07380251 Shown for Reference).

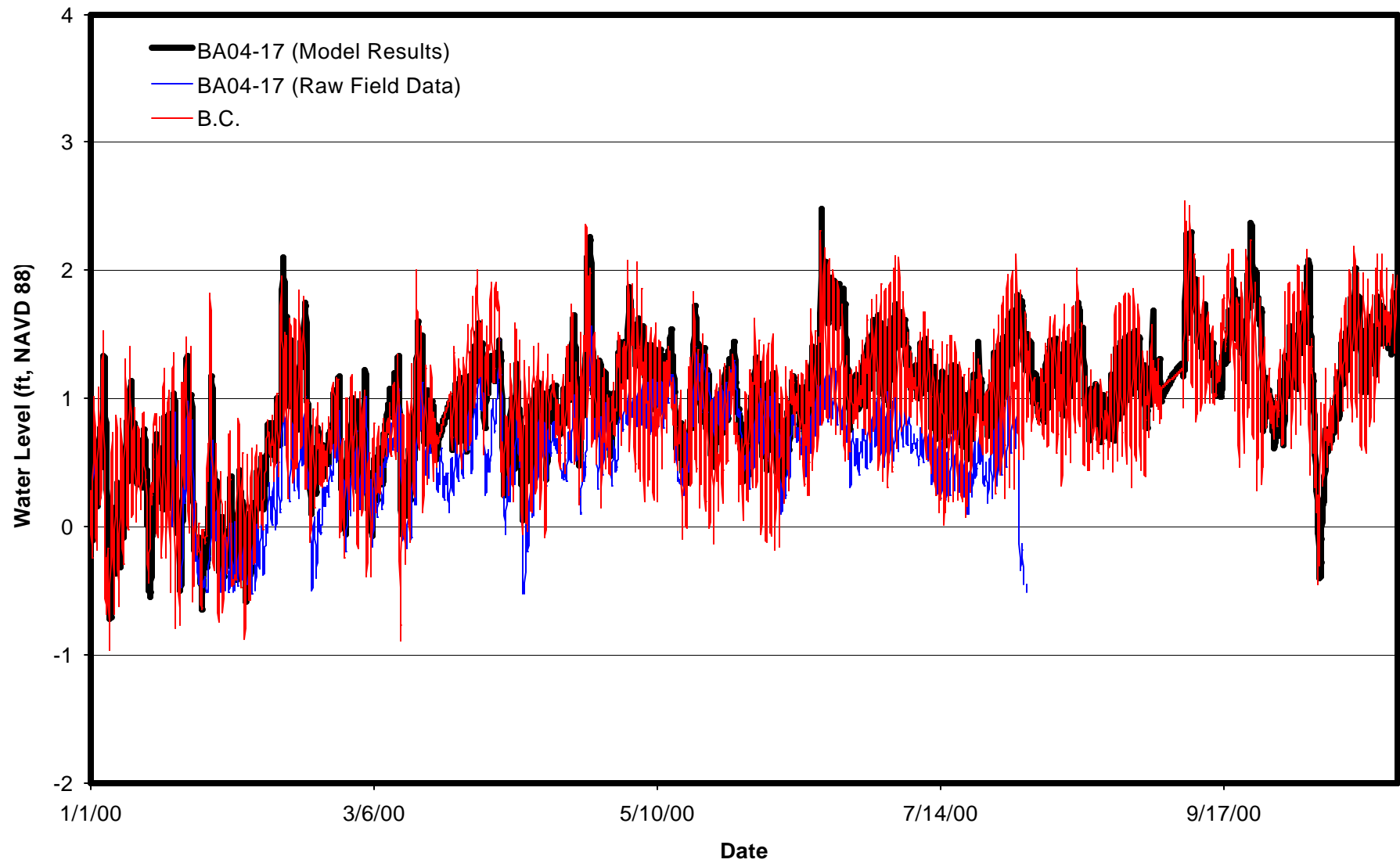


Figure 3.18: Comparison of Water Level Model Results Versus Raw Field Data at Gauge BA04-17 (B.C. - USGS 07380251 Shown for Reference).

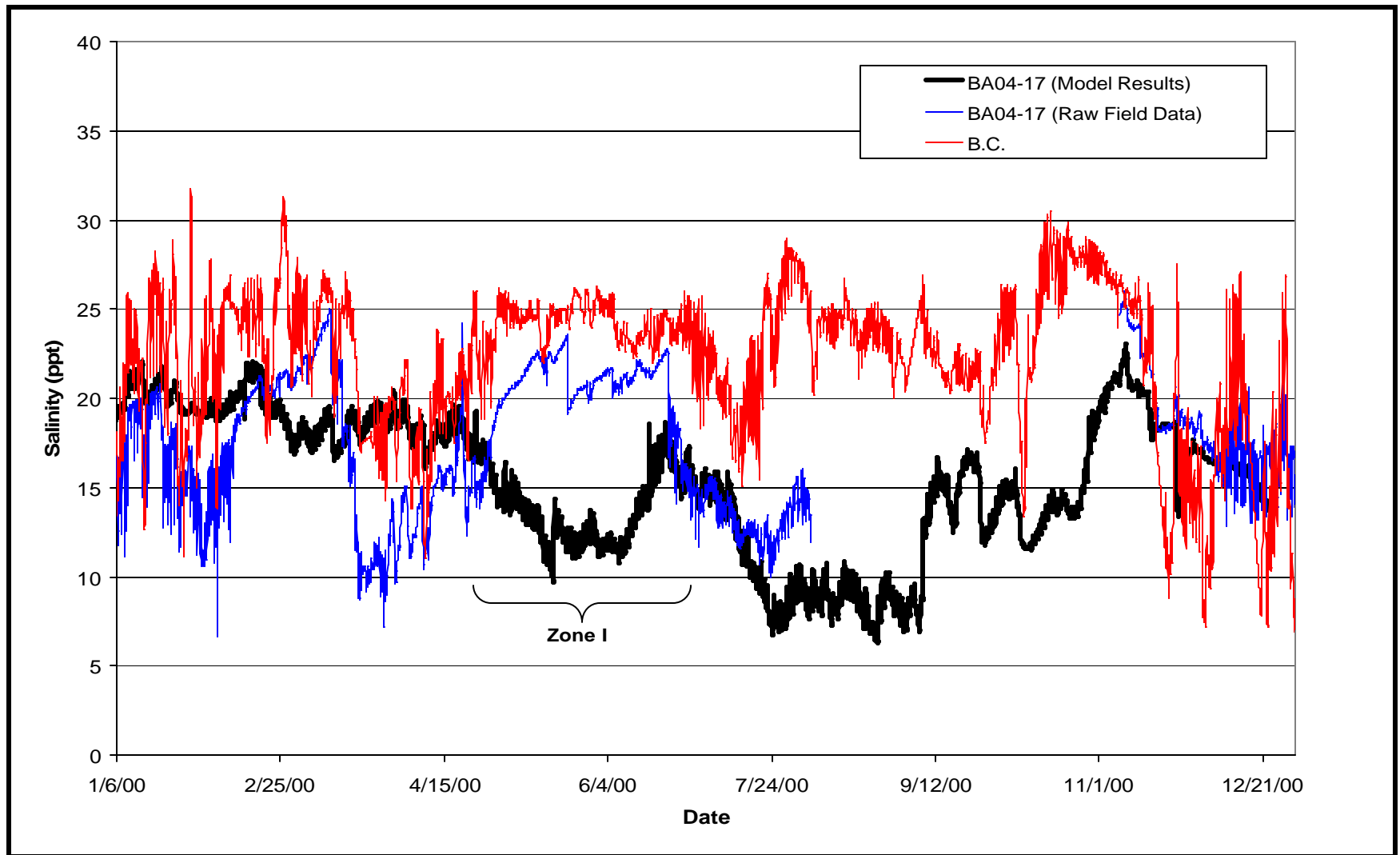


Figure 3.19: Comparison of Salinity Model Results Versus Raw Field Data at Gauge BA04-17 (B.C.- USGS 07380251 Shown for Reference).